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Technical Report
TR-2222-ENV

IN SITU BIOREMEDIATION OF MTBE IN GROUNDWATER

(ESTCP Project No. CU-0013)

by

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14. ABSTRACT

Treatment of MTBE-contaminated aquifers is difficult because the unique chemical properties of MTBE (relatively high soluble, relatively low sorption, relatively low Henry's Law Constant compared to BTEX compound properties) render most conventional groundwater treatment approaches ineffective or impracticable. Currently, conventional pump-and-treat (P&T) followed by aboveground water treatment and discharge is thought to be the only reliable option. However, P&T is known to be a slow source zone treatment option, it is maintenance-intensive, and a s a result is a relatively costly option at many sites. Preliminary American Petroleum Institute (API) estimated suggest that the presence of MTBE at a fuel release site could at least double the corrective action cost relative to at similar site without MTBE (API, 1997; Bauman, 1997).

This demonstration illustrates the potential of an innovative technology designed to contain dissolved MTBE groundwater plumes. In this technology, a biologically reactive groundwater flow-through barrier (the "bio-barrier") is established downgradient of a gasoline-spill source zone. Groundwater containing dissolved MTBE flows to, and through, the bio-barrier. As is passes through the bio-barrier, the MTBE is converted by microorganisms to innocuous by-products (carbon dioxide and water). Groundwater leaving the down-gradient edge of the treatment zone contains MTBE at concentrations less than or equal to the treatment target levels.

15. SUBJECT TERMS

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EXECUTIVE SUMMARY

Treatment of methyl tert-butyl ether (MTBE)-contaminated aquifers is difficult because of the unique chemical properties of MTBE (relatively high solubility, relatively low sorption, relatively low Henry's Law Constant compared to BTEX compound properties) render most conventional groundwater treatment approaches ineffective or impracticable. Currently, conventional pump and treat (P&T) followed by aboveground water treatment and discharge is thought to be the only reliable option. However, P&T is a slow source zone treatment option, is maintenance-intensive, and is a costly option at many sites. Preliminary American Petroleum Institute (API) estimates suggest that the presence of MTBE at a fuel release site could at least double the corrective action cost relative to a similar site without MTBE (API, 1997; Bauman, 1997).

This demonstration illustrates the potential of an innovative technology designed to contain dissolved MTBE groundwater plumes. In this technology, a biologically reactive groundwater flow-through barrier (the "bio-barrier") is established down gradient of a gasoline-spill source zone. Groundwater containing dissolved MTBE flows to, and through, the bio-barrier. As the groundwater passes through the bio-barrier, the MTBE is converted by microorganisms to innocuous by-products (carbon dioxide and water). Groundwater leaving the down gradient edge of the treatment zone contains MTBE at concentrations less than or equal to the treatment target levels.

The results of this demonstration are beneficial to the environmental profession because:

- This demonstration project is the first to document the cost and performance of a full-scale cost-effective remedy for the in situ treatment of an MTBE-impacted aquifer. Remediation by engineered in situ biodegradation was thought to be an unlikely candidate just a few years ago. This project demonstrates that MTBE-impacted groundwater can be remediated in situ by engineered aerobic biodegradation under natural-flow conditions. With respect to economics, the installation and operation costs associated with this innovative bio-barrier system are 66% lower than those of the existing large-scale pump and treat system that was also used for containment of the dissolved MTBE plume at NVBC, Port Hueneme, California.

- It has been suggested that aerobic MTBE biodegradation will not occur, or not be effective, in mixed MTBE-BTEX (benzene, toluene, ethyl-benzene, and xylenes) dissolved plumes. This project demonstrates that MTBE-impacted groundwater can be remediated along with BTEX components by aerobic biodegradation in a mixed MTBE-BTEX dissolved plume.

- This system has achieved an in situ treatment efficiency of >99.9% for dissolved MTBE and BTEX. Samples collected from downgradient monitoring wells now contain <5 µg/L MTBE and non-detectable levels of BTEX components.

Of greater importance is the fact that extensive performance data has been collected and this data is being used to generate best-practice design guidance and cost information for this technology.

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ABBREVIATIONS AND ACRONYMS

API	American Petroleum Institute
ARA	Applied Research Associates
ASU	Arizona State University
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
cfm	cubic feet per minute
DO	dissolved oxygen
DoD	Department of Defense
GC	gas chromatograph
IDW	investigation-derived waste
MDL	method detection limit
MTBE	methyl-tert-butyl ether
NFESC	Naval Facilities Engineering Service Center
OD	outer diameter
O&M	operation and maintenance
OSHA	Occupational Safety and Health
PELs	permissible exposure levels
QA/QC	quality assurance/quality control
SF_6	sulfur hexafluoride
SVE	soil vapor extraction
TBA	tert-butyl alcohol
TPH	total petroleum hydrocarbons
VOA	volatile organic analysis
VOC	volatile organic compounds

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Methyl tert-butyl ether (MTBE), a fuel oxygenate, has been added to gasoline since the late 1970's. Initially it was added at concentrations of about 2% by volume for octane enhancement, and recently it is being blended at concentrations of up to 15% by volume to meet today's cleaner burning fuel requirements. As a result, it is frequently found in groundwater beneath gasoline storage facilities.

Most states have only recently required monitoring for MTBE, so the frequency, magnitude, and spatial extent of groundwater impacts from MTBE has yet to be fully assessed. Due to its higher mobility and lower natural degradation potential, MTBE is expected to migrate farther and faster than other fuel components of concern (e.g., benzene, toluene, ethylbenzene, xylenes - BTEX). As an illustration, the MTBE plume emanating from the Naval Base Ventura County (NBVC), Port Hueneme service station is now over 500 feet wide and over a mile long. It outdistances the dissolved BTEX plume by over 4,000 feet. While plumes like that one are not typical, a number of similar length plumes have been identified: Vandenberg, AFB; Novato, CA; East Patchogue, NY and there are already a number of well-publicized municipal well-impacts: Santa Monica, CA; Lake Tahoe, CA; Marysville, CA; and Glennville, CA. In contrast, Happel, et al. (1998); Mace and Choi (1998); Reid, et al. (1999); and Wilson, et al. (2001) concluded that many MTBE plumes appear to not be much longer than their associated dissolved benzene plumes at this time. Their studies primarily involved analyses of available groundwater quality monitoring data from leaking underground storage tank (LUST) sites in California, Texas, Florida, and South Carolina. It is important to note that the authors also state that the available data was insufficient to assess MTBE plume stability, and that additional time-series data are needed. Our limited experience to date in characterizing dissolved MTBE plumes and reviewing data from MTBE-impacted sites suggests that vertical profiling of aquifers may be necessary to adequately assess some dissolved MTBE plumes, and consequently the data from conventional LUST site monitoring schemes may lead to incorrect conclusions regarding the extent of some dissolved MTBE plumes; this is especially true in areas with significant vertical gradients due to recharge and aquifer pumping.

Low taste and odor thresholds, coupled with possible human health effects, are causes of concern to drinking water utilities. Regulatory standards for MTBE in groundwater have yet to be set on a national level. Most states, however, have established groundwater action and cleanup levels for MTBE contamination. In the western states, the level is most often set at 20 µg/L (with the notable exception of California which has established 13 µg/L as its action level and 5 µg/L as a cleanup goal). The eastern states have established action levels ranging from 10 µg/L (Vermont) to 520 µg/L (Louisana), with the rest normally falling at 20, 40, or 70 µg/L. Several states have opted to wait for an EPA MCL to be established: Arizona, Colorado, North Dakota, South Dakota, Iowa, Mississippi, Georgia, Tennessee, and Kentucky. In order to prevent future contamination, 15 states have laws that will limit or ban the use of MTBE.

Treatment of MTBE-contaminated aquifers is challenging because it has a high aqueous solubility, a low organic carbon sorption coefficient, and a low Henry’s Law Constant compared

to other dissolved organic contaminants of interest at LUST sites (e.g., BTEX). Conventional above-ground groundwater treatment approaches are ineffective or impracticable for MTBE (Wilhelm, et al., 2002), and practitioners expect common in situ treatment methods (e.g., soil vapor extraction, in situ air sparging) to have limited effectiveness. Currently, conventional pump-and-treat (P&T) followed by aboveground water treatment and discharge is thought by many to be the only reliable option. However, P&T is known to be a slow source zone treatment option, it is maintenance-intensive, and as a result is a relatively costly MTBE treatment option at many sites. Preliminary American Petroleum Institute (API) estimates suggest that the presence of MTBE at a fuel release site could at least double the corrective action cost relative to a similar site without MTBE (API, 1997; Bauman, 1997). It should be noted that Bruce (2001) did achieve significant treatment of MTBE and other residual petroleum fuel hydrocarbons in soils and groundwater at the Port Hueneme site using in situ air sparging.

This issue is of relevance to the U. S. Environmental Protection Agency (EPA), state regulatory agencies, and the gasoline refining and marketing industry, all of which are desperately seeking practical solutions to this problem. The treatment of MTBE-impacted sites is of relevance to the Department of Defense (DOD) as gasoline is stored, transported, or dispensed at many military installations. MTBE is also being discovered in other fuels, albeit at lower concentrations (this is thought to be the result of shared pipeline use for multiple petroleum fuel products). The management and treatment of MTBE-impacted aquifers is of particular importance to DOD. In recent years, DOD has encouraged and demonstrated the use of in situ natural attenuation for the management of dissolved BTEX groundwater plumes at fuel spill sites.

Until recently, this approach had been gaining acceptance in the regulatory community; however, with the increased awareness of MTBE and its potential to cause more extensive impacts than BTEX, the acceptability of natural attenuation for sites containing MTBE is now being questioned by regulators. Without other practicable alternatives to pump and treat (P&T) at MTBE-impacted groundwater sites, or serviceable tools to monitor attenuation (Hunkeler, et al., 2001), the use and acceptance of natural attenuation as a remediation/aquifer management option may become limited in the near future. This concern was noted as a key issue by the DOD sponsored Lawrence Livermore National Laboratory Risk-Based Corrective Action Expert Committee that has reviewed corrective action plans for 10 DOD leaking underground storage tank sites in California (Rice, et al., 1998). There is clearly an immediate need to identify and explore more cost-effective treatment approaches for MTBE, especially those that can be conducted in situ or in conjunction with natural attenuation.

This innovative groundwater treatment demonstration involved the design, installation, and optimization of a large-scale bio-barrier for the in situ treatment of groundwater impacted by MTBE and other dissolved gasoline components. It was implemented at the NBVC, Port Hueneme, to prevent further contamination of ground water by MTBE leaching from gasoline-contaminated soils. The Port Hueneme site is well known because the dissolved MTBE plume is already 5,000 feet long and 500 feet wide, and because the Base has hosted a number of small-scale MTBE treatability studies in recent years.

The results of this demonstration are beneficial the environmental profession because:

- This demonstration project is the first to document the cost and performance of a full-scale cost-effective remedy for the in situ treatment of an MTBE-impacted aquifer. Remediation by engineered in situ biodegradation was thought to be an unlikely candidate just a few years ago. This project demonstrates that MTBE-impacted groundwater can be remediated in situ by engineered aerobic biodegradation under natural-flow conditions. With respect to economics, the installation and operation costs associated with this innovative bio-barrier system are 66% lower than those of the existing large-scale pump and treat system that was also implemented for containment of the dissolved MTBE plume at the Port Hueneme site.

- It has been suggested that aerobic MTBE biodegradation will not occur, or not be effective, in mixed MTBE-BTEX (benzene, toluene, ethyl-benzene, and xylenes) dissolved plumes. This project demonstrates that MTBE-impacted groundwater can be remediated along with BTEX components via aerobic biodegradation in a mixed MTBE-BTEX dissolved plume (Deeb, et al. 2001).

- This system has achieved an in situ treatment efficiency of >99.9% for dissolved MTBE and BTEX. Samples collected from downgradient monitoring wells now contain <5 µg/L MTBE and non-detectable levels of BTEX components.

Of greater importance is the fact that extensive performance data has been collected and this data is being used to generate best-practice design guidance and cost information for this technology.

1.2 OBJECTIVES OF THE DEMONSTRATION

Specific performance objectives are listed in Table 1.

Table 1. Demonstration Objectives

Objective	Product
Install and operate a full-scale MTBE bio-barrier across a mixed BTEX/MTBE dissolved plume, with sections of the bio-barrier corresponding to different possible design configurations. At a minimum, design configurations to be tested include a zone seeded with MTBE-degrading organisms and aerated with oxygen gas (bio-augmented), and a zone not seeded with any organisms, but aerated with oxygen gas (bio-stimulated).	A 500-foot long bio-barrier was installed at the toe of the immiscible source zone in the mixed MTBE/BTEX dissolved plume at the NBVC, Port Hueneme, CA. The bio-barrier was comprised of two different bioaugmented plots (oxygenated and seeded with two MTBE-degrading cultures), and two different types of bio-stimulated plots (one aerated and one oxygenated). Operation of the aeration/ oxygenation system began in late September 2000, and seeding took place in mid-December 2000.
Assess the reductions in MTBE, BTEX, and TPH concentrations achieved by the bio-barrier with time.	Over 400 wells were installed in August 2000 and approximately 225 of these wells were used for groundwater monitoring. These wells were monitored on a monthly to quarterly basis for

Objective	Product
	dissolved oxygen (DO), MTBE, and BTEX. Perodic quantification of tert-butyl-alcohol (TBA) also occurred. Results are shown in Section 4.3.
Assess the effectiveness of oxygen delivery to the target treatment zone.	Results from the monthly to quarterly monitoring events are shown in Section 4.3. The oxygen and air delivery created a stable, well-oxygenated treatment zone.
Collect economic information. Prepare a technology implementation manual and economic cost model for the technology.	The bio-barrier technology implementation manual will be completed in early 2003. The economic cost model is presented in Section 5 of this report.

1.3 REGULATORY DRIVERS

Regulatory standards for MTBE in groundwater have yet to be set on a national level. Most states, however, have established groundwater action and cleanup levels for MTBE contamination. In the western states, the level is most often set at 20 µg/L (with the notable exception of California which has established 13 µg/L as its action level and 5 µg/L as a cleanup goal). The eastern states have established action levels ranging from 10 µg/L (Vermont) to 520 µg/L (Louisiana), with the rest normally falling at 20, 40, or 70 µg/L. Several states have opted to wait for an EPA MCL to be established. In order to prevent future contamination, 15 states have laws that will limit or ban the use of MTBE (API, 2002).

1.4 STAKEHOLDER/END-USER ISSUES

There are regulatory questions concerning the injection of a microbial culture into an aquifer. Neither of the cultures used in this study, MC-100 and SC-100, were the source of any pathogenic bacteria. The Los Angeles Regional Water Quality Control Board has twice (August 1998 and December 2000) given permission to perform injections of these bacteria into the surficial aquifer at Port Hueneme.

CHAPTER 2. TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

In this technology, a biologically reactive groundwater flow-through barrier (the "bio-barrier") is established downgradient of a gasoline-spill source zone (the "source zone" is delineated by the presence of soils containing free-phase/non-aqueous phase gasoline). Groundwater containing dissolved MTBE flows to, and through, the bio-barrier. As the contaminated water flows through the bio-barrier, the MTBE is converted by microorganisms to innocuous by-products (carbon dioxide and water). Groundwater leaving the down-gradient edge of the treatment zone contains MTBE at concentrations less than or equal to the treatment target levels.

The reactive barrier is comprised of a line of gas injection wells. It was designed to create a stable zone of aeration/oxygenation spanning the width of the MTBE plume, while still allowing unimpeded flow of groundwater through the system. The major process components required for this technology include gas injection wells, timers, an oxygen generator (or air compressor), gas storage tanks, and groundwater monitoring wells (as shown in Figure 1).

Figure 1. Bio-barrier located at NBVC, Port Hueneme, California.

The objective of this work was to design and install a system that operates reliably and is capable of consistently reducing MTBE, TBA, and BTEX concentrations to <10 µg/L.

2.2 PREVIOUS TESTING OF THE TECHNOLOGY

The technology presented in Table 2 has been in development for over a decade.

Table 2. MC-100 and SC-100 Technology Development History

Development Phase	Approximate Time Frame	Sponsors/Participants
Enrichment of mixed culture and lab-scale flow-through reactor tests	1990 - 1993	Shell Oil Company
Development of BC-4 production reactor and large-scale flow-through reactor tests	1993 - 1998	Shell Oil Company
Lab physical model (sand column) studies	1996 - 1998	Shell Oil Company
In situ bioaugmentation demonstration at NCBC Port Hueneme, CA facility using the mixed culture MC-100 and oxygen gas injection	1998 – present	Equilon Enterprises LLC, Arizona State University, and NFESC
Growth of culture in large-scale reactor (MC-100) and isolation of pure culture (SC-100)	1999 – present	Equilon Enterprises
In situ bioaugmentation demonstration No. 2 at NCBC Port Hueneme, CA facility using mixed culture MC-100 and pure culture SC-100 and oxygenation with air.	2000 – present	Equilon Enterprises LLC, Arizona State University, and NFESC

In mid-1998, Arizona State University, in collaboration with Shell Global Solutions and the NFESC, installed the first MTBE bio-barrier at NBVC. Initially three 20-foot wide demonstration plots were installed; these included: (1 a control plot, (2) an oxygen injection-only plot, and (3) a bio-augmented (MC-100 seeded)/oxygen gas injection plot. All were placed far enough downgradient of the source zone that groundwater contained only MTBE and TBA in the vicinity of the pilot test plots.

Results from those tests were encouraging. Significant MTBE-concentration decreases were seen in the MC-100 seeded plot within 30 to 60 days. Influent MTBE concentrations ranging from 1,000 to 10,000 µg/L were significant reduced, so that down-gradient concentrations were between about 50 µg/L to less than detection levels (about 1 µg/L). The test plots have operated for almost four years without being re-seeded and without any apparent loss of MTBE-degrading activity. After about 240 days of operation, the oxygen-only plot did show signs of MTBE-degrading activity. Concentrations in that test plot eventually declined to <100 µg/L levels, suggesting successful biostimulation.

In January 2000, three additional 20-foot wide test plots were installed in the same vicinity, but cross-gradient from the original three test plots. The three additional plots were installed to

study the following conditions: (1) MC-100 and oxygenation using air, (2) SC-100 and oxygenation using oxygen gas, and (3) SC-100 and oxygenation using air. Data from this work has yet to be published, but these plots also achieved MTBE concentration reductions similar to those discussed above.

Figure 2 presents a photo of the ASU/Shell Global Solutions/NFESC pilot test plots. It shows the initial prototypes of the major process components of this technology: gas injection wells, timers, an oxygen generator (or air compressor), gas storage tanks, and groundwater monitoring wells.

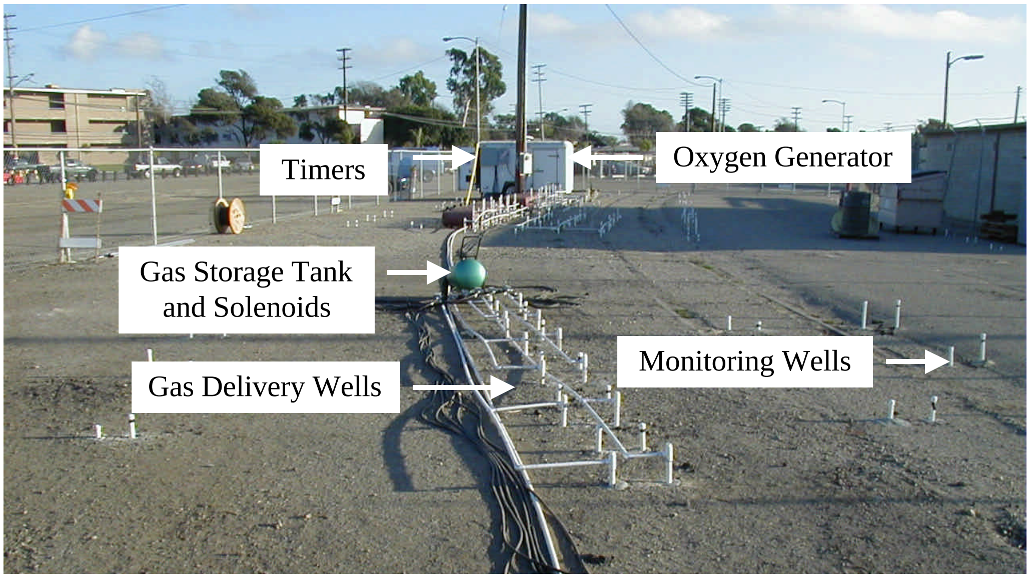

Figure 2. ASU/Shell Global Solutions/NFESC pilot-scale test plots, showing major process components.

Details of the first 240 days of operation of the three pilot-scale plots were presented by Salanitro, et al. (2000). Data from the second three pilot-scale plots using SC-100 are presented in a manuscript that is currently in preparation.

As the pilot-scale work focused on applications of this technology to an MTBE-only portion of the Port Hueneme plume, this ESTCP-sponsored full-scale demonstration focused on application of the technology to a mixed MTBE and BTEX (and other dissolved hydrocarbons) plume.

2.3 FACTORS AFFECTING COST AND PERFORMANCE

The major factors affecting costs associated with the implementation of a bio-barrier technology are:

- Soil characteristics (costs increase for finer-grained soils and increased heterogeneity).
- The need for bioaugmentation or sufficiency of bio-stimulation.

- Depth to ground water (costs increase with depth).
- Width of the plume (costs increase as the treatment width increases).
- Type of installation required at the site (i.e., aboveground or underground).

Based on the full-scale demonstration costs at Port Hueneme and input from Shell Global Solutions (US) Inc., the projected costs to install a bio-barrier at a site ranged from $800/linear foot to $1,050/linear foot for aquifers less than 30 feet below ground surface (bgs). The well installation costs will increase for aquifers more than 30 feet bgs because the utility and efficiency of direct push technology is reduced, and at some depths conventional drilling and installation techniques would be required. In the Excel spreadsheet, the projected future length of the bio-barrier system can be adjusted to provide cost estimates for different plume widths.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

At this point in time, the profession regards pump-and-treat (P&T; groundwater extraction followed by aboveground treatment) to be the only proven method for MTBE-impacted aquifer remediation. As conventional aboveground groundwater treatment technologies (e.g., carbon adsorption, air stripping, etc.) are much less effective for MTBE than for BTEX compounds, P&T could have high operation and maintenance requirements.

In comparison, the use of an in situ treatment technology eliminates the need for groundwater extraction, aboveground treatment, and discharge. Furthermore, the equipment associated with this bioremediation/bioaugmentation technology includes the items shown in Figure 2. This equipment is necessary to maintain the treatment zone in a well-oxygenated state. In addition, MTBE is mineralized in situ to innocuous products (CO_2 and H_2O) by this technology, rather than being transferred to another medium (as is done in most pump and treat and air sparging applications).

The limitation of this technology is that it is applicable to settings where: (a) the treatment zone can be maintained in a well oxygenated state, and (b) either an MTBE-degrading culture can be delivered, or indigenous MTBE degraders can be stimulated to a level of sufficient activity. Its applicability is limited primarily by the geologic setting (e.g., soil types, heterogeneity, depth to groundwater, etc.), in much the same way as many other in situ technologies (e.g., in situ air sparging).

MTBE remediation goals are still being established and revised in many states; drinking water standards range from the sub-10 µg/L to 100s of µg/L concentrations. The investigators are not yet aware of any remediation goals established for MTBE bio-barrier applications. One possibility is the requirement that groundwater leaving the treatment zone meet drinking water standards, while another possibility is that higher concentrations will be acceptable after consideration of dispersion downgradient of the bio-barrier. Pilot tests conducted at Port Hueneme showed that a bio-barrier can reduce concentrations of MTBE from 1,000 to 10,000 µg/L down to <10 µg/L concentrations in bioaugmented plots and <100 µg/L in bio-stimulated plots.

CHAPTER 3. DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The overall objective of this demonstration is to implement and assess the performance of an innovative technology that is designed to contain dissolved MTBE groundwater plumes. The performance objectives are listed in Table 3.

Table 3. Performance Objectives

Objective	Primary Performance Criteria	Expected Performance (metric)	Actual Performance (Objective met?)
Qualitative	Reliability	"Up-time"	There were no instances of breakthrough once the bio-barrier was established
	Ease of use	Base acceptance	NBVC has accepted the bio-barrier as its plume treatment technology
Quantitative	Time to maximum concentration reduction	Within 8 months	Maximum concentration reduction was established within 6 to 7 months for all sections (aeration, oxygenation, and microbes+ oxygenation) of the barrier
	Concentration reductions across barrier	> 90% for the most concentrated areas	Concentrations were reduced to less than 5 µg/L across the site
	Meet regulatory standard	Varies by location*	For California, the standard for MTBE is 13µg/L. Contaminant concentrations leaving the barrier were less than 5 µg/L.
	Reliability	"Up-time"	There were no instances of breakthrough once the bio-barrier was established

*With respect to remedial goals, these vary by state and by local lead regulatory agency, and are often set on a site-specific basis. To date, there has been little enforcement, except in cases where potable supply wells have been impacted. In addition, revisions to state standards are still occurring. It is difficult at this time to cite any remedial goals; however, proposed drinking water standards have ranged from about 1 µg/L to about 200 µg/L. Proposed values for California fall in the 0.5 to 10 µg/L range.

Remedial goals also vary in terms of the compliance location where the goal must be met and how much vertical averaging is allowed. At some sites, it may be acceptable to have concentrations measured immediately down-gradient of the bio-barrier exceed drinking water standards by a factor of 10 or 100, provided that other mechanisms (i.e., dispersion and dilution) act to further lower the concentration measured at the compliance point.

Fortunately, the design of this demonstration does not depend on any specific remedial goal. The system is being designed based on experience to achieve the best practicable performance, and later, the actual measured performance will be compared to nation-wide remedial goals in existence at the end of this study. Primary objectives of this demonstration include:

- Install and operate a full-scale MTBE bio-barrier across a mixed BTEX/MTBE dissolved plume, with sections of the bio-barrier corresponding to different possible design configurations. At a minimum, design configurations to be tested include a zone seeded with MTBE-degrading organisms and aerated with oxygen gas (bio-augmented), and a zone not seeded with any organisms, but aerated with oxygen gas (bio-stimulated).

- Achieve sufficient oxygenation (>4 mg/L dissolved oxygen) in the target treatment zone.

- Achieve reduction of MTBE concentrations to levels consistent with current and proposed remedial goals across the United States (<200 µg/L).

- While operating the system, minimize downtime and maximize efficiency of operation.

Secondary objectives include:

- Assess the reductions in MTBE, BTEX, and TPH concentrations achieved by the bio-barrier with time.

- Assess the effectiveness of oxygen delivery to the target treatment zone.

- Collect information needed for an economic assessment of the technology.

Technology effectiveness will be quantified in terms of:

- Concentration reductions across the bio-barrier.
- Time to achieve maximum concentration reductions.
- Reliability (up-time) of the system.

3.2 TEST SITE SELECTION

The following criteria were used to select a site:

1. Willingness of the facility to host the test site and assist with disposal of any waste soils or groundwater.

2. Facility's ability to provide personnel to perform weekly checks on the system;

3. Power and utilities are easily accessible.

4. A good working relationship between the facility and the local environmental regulators.

5. Easy site assess (i.e., no restricted hours for site access and little or no foot or vehicle traffic in the area).

The following specific criteria were used for site selection:

1. Site with sandy soil with depth to groundwater of 10 to 25 feet bgs.

2. BTEX/MTBE dissolved plume with 100 to 10,000 µg/L concentrations emanating from gasoline-contaminated soils,

3. Access to the downgradient edge of the source zone.

4. Groundwater velocities >0.1 foot per day.

Condition 1 is necessary so that cost-effective direct-push drilling and well installation techniques can be used and so that groundwater sampling can be achieved with peristaltic pumps. Conditions 2 and 3 are necessary as the objective of this demonstration is to demonstrate and assess performance across a mixed MTBE/BTEX dissolved plume. Condition 4 is necessary to ensure that downgradient water quality changes can be observed within the lifetime of this project.

3.3 TEST SITE DESCRIPITION

The Naval Base Ventura County NEX service station is at the southeast intersection of 23rd Avenue and Dodson Street (Figure 3). When the NEX service station started operating in 1950, there were two 7,400-gallon underground storage tanks (USTs) with installations of six additional USTs. Based on inventory records, approximately 4,000 gallons of leaded gasoline and 6,800 gallons of premium-unleaded gasoline were released into the subsurface between September 1984 and March 1985 due to faulty transfer lines between the tanks and dispensers. The gasoline liquid spread out on top of the shallow aquifer, resulting in a 9-acre gasoline source area plume and a dissolved MTBE plume extending about 5,000 feet. The dissolved plume is,

for the most part, under open hardstands (parade ground, parking lots, and storage areas) with a few industrial buildings and one military housing building.

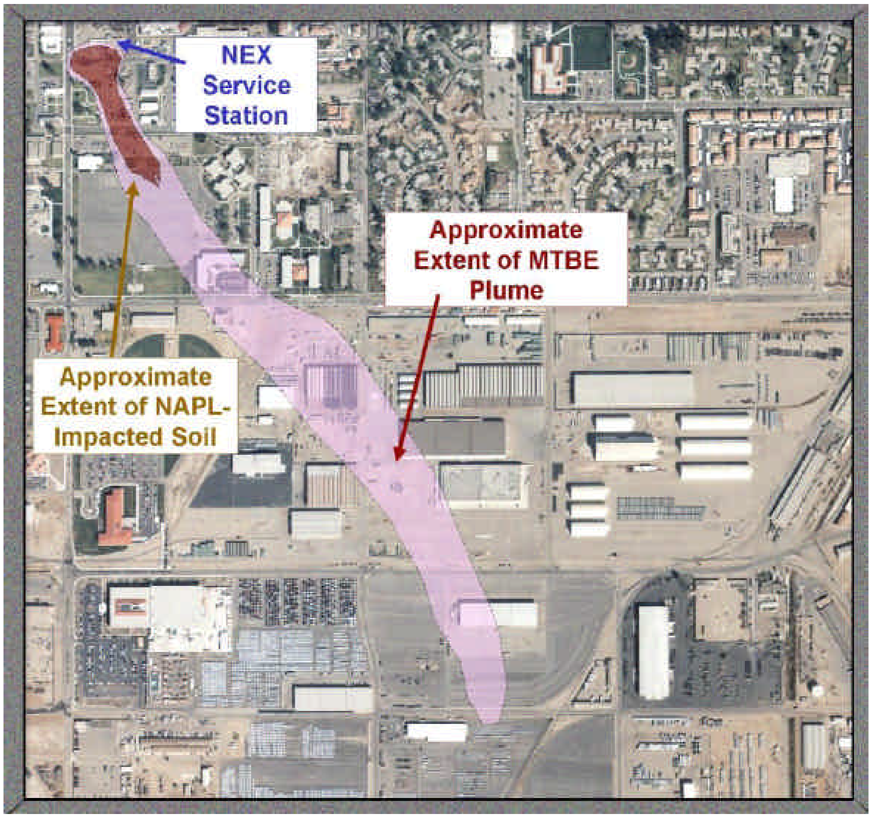

Figure 3. Site map shows the extent of the source zone and the dissolved MTBE plume. (North is to the left in this orientation; the dissolved plume is about 5,000 feet long).

Free-product (mobile) gasoline has not been detected in any of the on-site wells associated with the NEX service station release. Trapped, residual gasoline (as NAPL) is present in the upper 3 feet of the aquifer throughout the "source zone." Portions of the impacted source were used for other technology demonstrations in the past, including: Groundwater pump and treat, groundwater recirculation wells, and in situ air sparging/vapor extraction. For the most part, these technologies were conducted several hundred feet up-gradient of the proposed test location and their past use did not affect this demonstration project (since down-gradient source areas were unaffected). To date, no technologies have been applied at the immediate down-gradient edge of the source zone.

Concentrations of MTBE in the vicinity of source zone soils are approximately 10,000 µg/L, decreasing to approximately 1,000 µg/L and lower in moving cross-gradient away from source zone soils. BTEX concentrations are approximately 1,000 µg/L (each component) in the vicinity of source zone soils.

The ground surface at the demonstration site is underlain by approximately 300 feet of unconsolidated clay, silt, sand, and gravel. The geology within 30 feet of the ground surface,

consists of unconsolidated sands, silts, and clays with minor amounts of gravel and fill material. Silty fill material extends from ground surface to about 7 to 9 feet bgs. Below that, medium-grained sands with some gravel are encountered down to 18 to 20 ft bgs, and a clay aquitard is encountered at about 20 feet bgs. The shallow aquifer of interest is unconfined and the depth to groundwater is approximately 8 ft bgs, with seasonal variations of about a foot. The gasoline-containing soils are generally found in the sand just below the fill layer from about 9 to 12 feet bgs.

In general, groundwater in this aquifer flows to the southwest with gradients ranging from approximately 0.001 to 0.003 ft/ft. Transmissivity values ranging from 19,000 to 45,000 gal/day/ft have been reported. Hydraulic conductivity values are estimated to range from 1,300 to 3,000 gal/day/ft. Groundwater flow velocity estimates range from 230 to 1,450 feet/year, assuming a porosity of 35%. Recent tracer studies conducted by Amerson and Johnson (2003) in the vicinity of the proposed site, demonstrated that groundwater velocities ranged from about 280 to 560 feet/year, with velocities increasing with aquifer depth. Based on the observed plume length and time since the gasoline release, a groundwater flow velocity estimate of about 300 feet/year can be calculated; however, this value is assumed to be representative of the highest flow velocity for this groundwater system. Data from the Shell Global Solutions sponsored pilot tests suggest that velocities for some groundwater flow paths could be 1/3 to 1/10 of the values discussed above.

3.4 PRE-DEMONSTRATION SAMPLING AND ANALYSIS

Through other projects, the investigators (and others) have already done extensive research at this facility and much was already known about the local hydrology and general characteristics of the NEX plume (e.g., spatial extent, concentration ranges, and temporal trends). What was not known with accuracy, however, was the location of the down-gradient edge of the gasoline-containing source zone soils. The approximate location was known, but additional pre-test sampling was necessary for proper location of the down-gradient edge.

The down-gradient edge of the gasoline-containing source zone soils was expected to be beneath the Parade Ground. The sampling program followed a trial-and-error approach, considering the direction of groundwater flow inferred from dissolved plume data and experience at the site. In brief:

- An initial guess was used as the starting point. A soil and groundwater sample was collected at that location, and chemical analysis was conducted on site.

- Based on the results of that sample location, the next sample was collected approximately 50 feet up and down-gradient of the first location. Chemical analyses were conducted on site.

- This step was repeated until the approximate location of the down-gradient edge of the source zone soils was located.

- Samples were collected at about every 50 feet cross-gradient until the width of the MTBE and BTEX plumes were defined (down to about 5 µg/L, or background levels).

- Additional samples on 25-foot spacings were collected to better define the width of the BTEX plume and the approximate location of the down gradient edge of the source zone soils.

Samples were collected by direct-push (e.g., Geoprobe™ techniques). Groundwater samples were analyzed on-site for dissolved hydrocarbon concentrations (MTBE, BTEX, TPH) and for dissolved oxygen; soil samples were assessed qualitatively for staining and gasoline odors, and were analyzed for TPH. Delineation was done with 19 sampling locations.

Our criteria for defining source zone soils were the combination of soil staining, gasoline odors, and elevated TPH concentrations in soil. High dissolved MTBE and BTEX concentrations (>1 mg/L) without soil staining or elevated soil TPH concentrations were considered indicative of locations immediately down-gradient of the source zone soils.

No effort was made to identify the presence of indigenous MTBE degraders during this pre-demonstration sampling. Previous microcosm studies had already identified low populations of MTBE-degraders in Port Hueneme soils and groundwater. A separate study was conducted to see if the occurrence and numbers of indigenous MTBE degraders correlate with location inside (and outside) the plume at Port Hueneme.

3.5 TESTING AND EVALUATION PLAN

3.5.1 Demonstration Installation and Startup

As discussed above, this technology demonstration involved installing a biologically reactive groundwater flow-through barrier (the "bio-barrier") in accordance with the NETTS Port Hueneme Health and Safety Plan, Appendix B. The basic components of the system include gas injection wells, timers, an oxygen generator (or air compressor), gas storage tanks, and groundwater monitoring wells. It was critical that the bio-barrier be installed down-gradient of a gasoline-spill source zone (and not across gasoline-containing soils). The basic sequence of activities involved:

- Delineating the down-gradient edge of the source zone
- Selecting the well locations and piping manifolds
- Purchasing the equipment
- Building the system
- Monitoring the baseline
- Operating the system
- Monitoring the performance
- Reporting the results

Each of these activities is discussed in more detail:

Delineating Source Zone. The down-gradient edge of the source zone was delineated using data collected during soil and groundwater sampling. A direct-push GeoProbe™ rig was used to collect continuous 3-foot soil samples across the smear zone. From previous studies, it is known that the smear zone is encountered at about 3-foot intervals located below the silt (fill)/sand interface (approximately 9 to 12 feet bgs). These were photographed and qualitative indicators of gasoline, such as staining and odor, were noted. Previous experiences at this facility indicate that the source zone areas can be easily defined by these qualitative indicators. However, quantitative data were also collected. At least two sub-samples per core will be collected and analyzed for total hydrocarbons (TPH) in the field by a methanol extraction/GC-FID method.

Groundwater samples were collected as well and analyzed in the field by a heated headspace/GC-FID method. MTBE, BTEX, and total hydrocarbon concentrations were recorded.

All GC-FID analyses were conducted on a dedicated SRI Instruments Model 8610C gas chromatograph using a DB-1 type capillary column. The instrument was calibrated each day at least three different concentrations spanning the concentration range of interest (e.g., 100; 1,000; 10,000 mg/kg-soil for methanol-soil analyses and 1 to 10,000 µg/L for dissolved concentrations). In addition, we analyzed calibration samples during the day to detect any instrument drift. Reporting levels were established based on the calibration results. For this instrument, reporting levels of about 100 to 200 mg-TPH/kg-soil were possible for the methanol-soil analysis and reporting levels of 1 to 5 µg/L were used for the BTEX compounds and MTBE in groundwater.

The exploded view shown in Figure 4, details the locations of monitoring and gas injection wells installed in August 2000; each "+" represents paired shallow and deep wells). Groundwater flows in the direction of the two arrows below the figure. The lateral dimensions are shown in feet from the northernmost well, and the vertical dimensions are also in feet measured from the gas injection wells row.

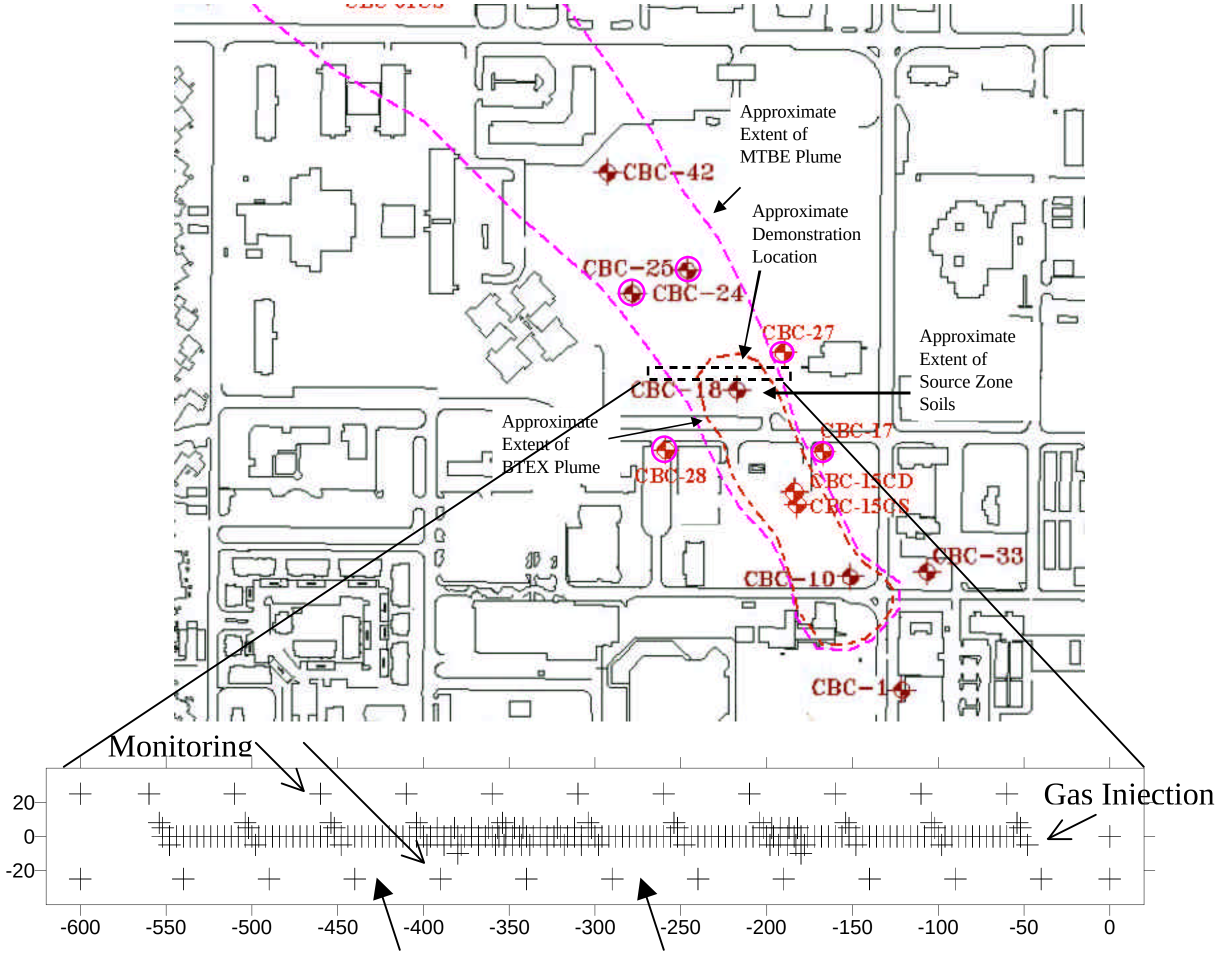

Figure 4. Plan view map showing approximate locations of the MTBE plume, BTEX plume, pre-existing wells, and demonstration site location.

Selecting Well Locations and Piping Manifolds. Figure 5 shows the well locations for the demonstration system. Pre-existing data suggested that the groundwater plume was about 300 feet wide in the proposed study area. Preliminary sampling showed that the plume was closer to 500 feet wide.

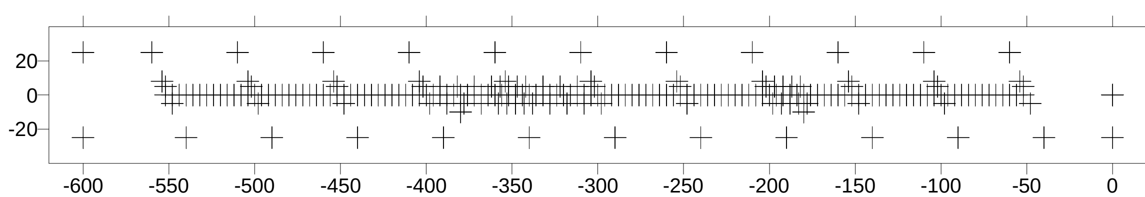

Figure 5. Plan view of well locations for the bio-barrier system.

In general, the design scheme included the following.

- System components include up- and down-gradient groundwater monitoring wells, gas injection wells, an oxygen generator, and a piping manifold.

- All groundwater monitoring wells installed as multi-level pairs that sample the upper and lower 5 feet of the aquifer (approx. 10 to15 feet bgs and 15 to 20 feet bgs screened intervals); all constructed from 3/4-inch diameter threaded PVC using 0.010 slot well screen.

- Groundwater monitoring wells spaced 50 feet apart laterally and at two or three distances up and down-gradient of the biobarrier as shown in Figure 5.

- Gas injection wells installed at two depths: 18 to 20 feet bgs and 14 to 15 feet bgs (approximately), and a gas injection well placed roughly every 2 feet along the bio-barrier; all constructed from 3/4-inch diameter threaded PVC using 0.010 slot well screen.

- In this modular design (Figure 6), oxygen (or air) is not injected at any specific flow rate. Instead, it is injected as a very short duration pulse approximately every 6 hours. A satellite 20-gallon oxygen storage tank is charged to approximately 45 psi by the oxygen generator or compressor, and then its contents are discharged to two wells at once. In these tests, complete discharge occurred within about 30 seconds, which corresponds to a short-term flow rate of about 10 ft^3/min per well. There is a satellite gas storage tank placed every 20 feet, and each satellite gas storage tank provides gas to a total of six pairs of wells (but only to one pair at a time).

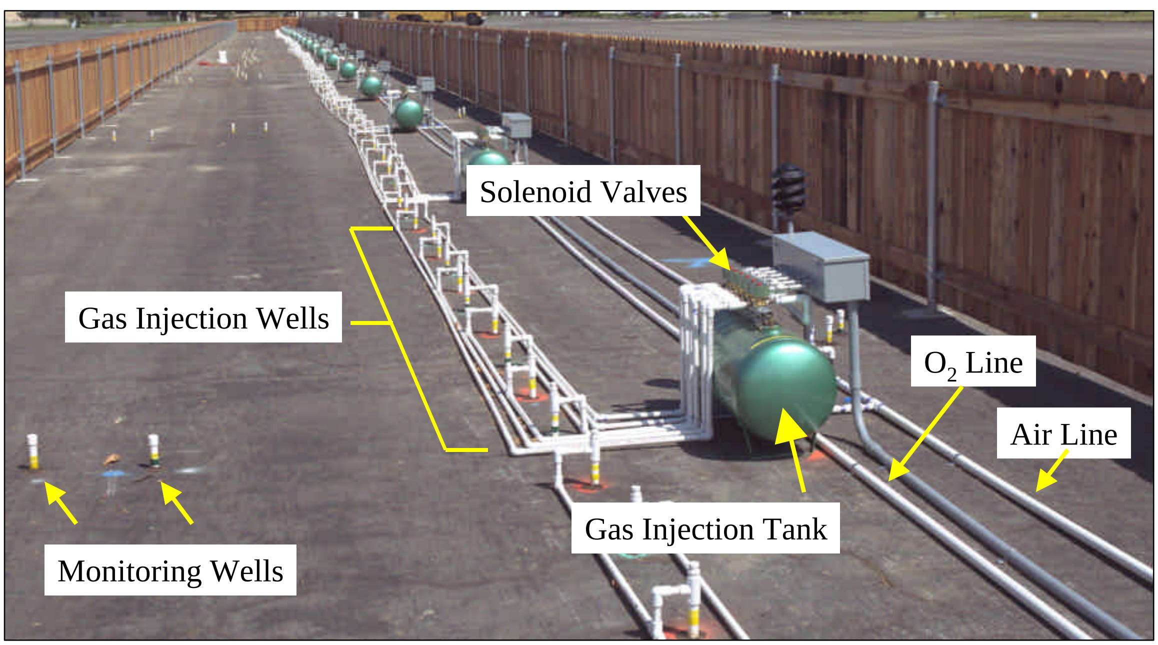

Figure 6. Details of a gas injection module.

Purchasing Equipment. Most of the equipment and supplies required for the test are readily-available off-the-shelf items like PVC piping and fittings, PVC well-screen material, gas storage tanks, pressure gauges, solenoids, and timers. The oxygen generator is the only major piece of equipment that is not an off-the-shelf item and will have to be constructed for this project. Specifications for the oxygen generator included an average oxygen-generating capacity of 100 to 200 standard cubic foot per hour (SCFH) at a delivery pressure of 60 psig. The unit was mounted in a weatherproof container.

Building the System. Building the system was done in three phases.

1. During the first phase, all monitoring and gas injection wells were installed by direct-push (e.g., Geoprobe™) techniques. In this approach, 3/4-inch threaded PVC casing and screens were installed through the inside of a drive rod, which was then withdrawn, leaving the well in place. The sandy upper aquifer at Port Hueneme is self-sealing, so no well packing material was necessary; the annulus remaining in the silty vadose zone was filled in with bentonite chips. Monitoring wells were installed across the upper and lower 5 feet of the aquifer (10 to 15 feet bgs and 15 to 20 feet bgs). All well screens were 0.010 slot PVC screens. Gas injection wells were installed at 18 to 20 feet bgs and 14 to 15 bgs (approx), and a gas injection well was placed roughly every 2 feet along the bio-barrier; all was constructed from 3/4-inch diameter threaded PVC using 0.010 slot well screen.

2. During the second phase, the oxygen injection system was installed and operated for 2 two months prior to the third phase of construction. One-half inch PVC and PVC connections were used for gas delivery manifolding. The timer solenoid valve system used standard 110-volt timers and solenoids.

3. During the third phase of construction, inoculation of biological material (grown at the Shell Westhollow Technology Center) occurred. This was done by direct injection of culture material diluted to 2.5 g-TSS/mL through drive-point rods. Five-gallon injections of MTBE-degrading culture were done at 1-foot intervals between 10 to 20 feet bgs. The lateral spacing of injections was 1 foot. The area selected for inoculation was by the barrier (the area ranged from 275 to 415 feet south of the northernmost well).

Monitoring the Baseline. Baseline monitoring included the groundwater data collected during the source zone delineation, as well as:

1. A round of groundwater sampling and analysis over a 1-month period after installation of the monitoring wells (Phase 1 of construction).

2. Two rounds of groundwater sampling and analysis over a 2-month period prior to inoculation with the MTBE-degrading culture, after installation and start-up of the operation of the oxygen injection system

Groundwater sampling involved measuring the dissolved oxygen using a flow-through cell and a YSI field dissolved oxygen meter. Samples were collected in zero-headspace VOA vials for analysis of MTBE and BTEX by GC-FID headspace method as described. All analyses were conducted on-site within 48 hours of sample collection.

During the baseline monitoring samples were collected from all monitoring wells and from approximately 20% of the gas injection wells. Approximately 10% replicate samples were collected.

Operating the System. System operation began in two phases: First the oxygen delivery system was operated to create a well-oxygenated treatment zone prior to seeding, and second the system continued to operate after seeding. During the initial phase of operation, system parameters (timing sequence and operating pressures) were monitored to ensure adequate oxygenation (>4 mg/L dissolved oxygen) in the bio-barrier, while minimizing the oxygen gas delivery rate.

The system's operation was relatively simple. Oxygen was injected four times each day, as controlled by a system of automatic timers and solenoids. The volume of gas injected each time was approximately 2 to 3 cubic feet per well.

Monitoring the Performance. Performance monitoring consists of the combination of groundwater sampling and system inspection. These are summarized in Table 4.

Table 4. Performance Measurements

Measurement	Purpose	Frequency
Visual inspection	Verification of system operation - track system downtime	Daily
Record of timer sequences and operating pressures	Track operating conditions	Whenever changes are made to the timer sequence or operating pressure
Groundwater sampling for dissolved oxygen	Assess performance of the oxygen delivery system	Monthly (initially), then every 2 months after 3 months of operation
Groundwater sampling for MTBE, BTEX, TBA, TPH analyses	Assess performance of the biobarrier	Monthly (initially), then every 2 months after 3 months of operation
Groundwater elevations	Track changes in groundwater levels	Monthly (initially), then every 2 months after 2 months of operation
Tracer test	Assess groundwater flow relative to initial conditions	Once after 3 months of system operation

3.5.2 Period of Operation

Table 5 shows the dates and duration of each phase/activity of the demonstration.

Table 5. Demonstration Activities

Date	Activity	Specifics
May 16-19, 2000	Plume delineation activities	Soil and groundwater testing
June 20- December 2000	Plume delineation activities	Microcosm testing
June-September 2000	Purchase of equipment	
August 5-22, 2000	Selection of well locations, system construction	Well installation
August 9-22, 2000	Baseline monitoring	Groundwater sampling from all wells
August -September 2000	System construction	Assembly and installation of piping and machinery
September 16, 2000	Baseline monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
September 22, 2000	Public relations	Ribbon-cutting ceremony
September 22, 2000 to present	System operation, Phase I	Oxygen/air injection system turned on
December 6, 2000	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
December 6-10, 2000	System operation, Phase II	Injection of MC-100 into the subsurface
December 12-15, 2000	System operation, Phase II	Injection of SC-100 into the subsurface
January 22, 2001	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells (5 samples sent to CAPCO Analytical Labs)
February 15, 2001	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells (5 samples sent to CAPCO Analytical Labs)
March 12, 2001	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
May 29, 2001	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
July 24, 2001	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
September 20, 2001	System monitoring	Groundwater sampling from 25 monitoring wells
October 13, 2001	System monitoring	Groundwater sampling from all

Date	Activity	Specifics
		monitoring wells/20% gas injection wells
January 22, 2002	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells (5 samples sent to CAPCO Analytical Labs)
March 31, 2002	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
June 13, 2002	System monitoring	Groundwater sampling from 25 monitoring wells
August 1, 2002	System monitoring	Groundwater sampling from 25 monitoring wells
November 2002	System monitoring	Groundwater sampling from all monitoring wells/20% gas injection wells
December 1, 2002	End of field activities	Bio-barrier turned over to the custody of NBVC personnel

3.5.3 Amount/Treatment Rate of Material to be Treated

Assuming an average groundwater flow rate of 0.3 feet per day, this barrier treated approximately 11,000 gallons of water per day. The range of flow rates measured in this aquifer during this study ranged from 0.1 to 0.3 feet per day. Previous studies estimated flow rates of up to a foot per day (meaning the barrier treated as much as 37,000 gallons per day). This water ranged in influent concentrations from 0.001 µg/L of MTBE to approximately 20,000 µg/L of MTBE.

3.5.4 Residuals Handling

No residuals were generated as a product of this technology.

3.5.5 Operating Parameters for this Technology

The barrier has operated continually from September 22, 2000 to the present. System operation began in two phase: The oxygen delivery system was operated to create a well-oxygenated treatment zone prior to seeding, and then the system continued to operate after seeding.

During this first phase of operation, system parameters (timing sequence and operating pressures) were adjusted to ensure adequate oxygenation (>4 mg/L dissolved oxygen) in the bio-barrier, while minimizing the oxygen gas delivery rate. System operation was relatively simple. Oxygen was injected four times each day, controlled by a system of automatic timers and solenoids. The volume of gas injected each time was approximately 2 to 3 cubic feet per well.

On-site personnel visually inspected the system for about 15 minutes each day on normal working days in order to verify that the oxygen generator and timer-solenoid systems were operating properly. The operation was visually inspected by checking the display on the

compressor to ensure that the unit had not shut down; checking the pressures on the compressor air storage tank and oxygen generator; checking the pressures on the satellite storage tanks; and listening for the solenoid operation.

The timer sequence and solenoid operation were verified once every few weeks by watching the system's operation for 2 hours.

Based on previous experience at the pilot test sites, the main sources of system upsets were compressor failures resulting from electrical blackouts or the compressor overheating. There were problems associated with solenoid timer-sequence problems and these sometimes caused the compressor to overheat.

System upsets due to electrical blackouts were easily fixed by restarting the compressor per the manufacturer's instructions. Overheating of the compressor was often caused by the ventilation system malfunctioning. Again, these are easily remedied by replacing the parts. A compressor service company was on contract for routine maintenance and repair.

Reprogramming the timer would solve any sequence problems. If the timer would fail again, another timer could be obtained within a couple of days.

Given the nature of the oxygen delivery system used (trapped gas) and our experiences at the pilot test sites, system upsets of about a week in duration can be easily tolerated by the biological barrier.

System non-performance, as measured by concentration reductions through the bio-barier, is linked to oxygenation and microbial activity. Of the two, only the first is controllable to any degree once the system is installed. This is done through well spacing, well-screen interval selection, and injection frequency. If there was no performance, the first course of action would be to alter the gas injection frequency and then see if that is sufficient. If not, additional gas delivery well installation would be considered.

3.5.6 Experimental Design

This technology followed a simple design path in order to meet its objectives.

The first objective was to delineate the contaminant source zone. To determine the extent of contamination by immiscible product, 19 continuous soil cores were taken. The first core was placed at the estimated location of the leading edge of the source zone. Further cores were taken by stepping out at 25- to 50-foot intervals until the resolution of the source area was within 10 feet.

The second objective was to create an oxygenated zone spanning the width and depth of the aquifer just beyond the edge of the contaminant source zone. Deep and shallow gas injection wells were put in on 4-foot centers spanning the entire 500-foot width of the plume (for a total of 252 gas injection wells). This demonstration, at 500 feet, was a full-scale system. Most remediation systems at UST sites will be about 100 to 200 feet in length. The demonstration

system was designed in a modular format (with 24-foot long replicated treatment systems) that can be easily scaled to different sizes. An important redundancy feature in this design is the gas injection system. Dissolved oxygen levels in the areas where pure oxygen was injected are in excess of 40 mg-oxygen/L-groundwater, and there is a reservoir of trapped gas pockets that can continue to feed oxygen to groundwater. This can provide oxygen for several days if there is equipment failure, and there will not be any catastrophic change in dissolved groundwater oxygen concentration (levels below 4 mg-oxygen/L-water).

To compensate for potential vertical variations in aquifer aeration (due to soil heterogeneity or well operation), the gas injection wells were spaced at 4-foot intervals in both the deep and shallow portions of the aquifer. This is a very conservative spacing, and likely the system would operate successfully with a larger spacing. The 4-foot spacing was selected for this site because the costs associated with well installation were minimal.

Finally, performance monitoring consisted of groundwater sampling and system inspection. These are summarized in Table 4.

3.5.7 Sampling Plan

This section provides an overview of the sampling operations, including the contaminants for which analyses will be performed. Sampling procedures will comply with the demonstration's Quality Assurance Plan (see Appendix A).

All analyses will be conducted on-site with portable field equipment (dissolved oxygen and water level measurements) and a dedicated gas chromatograph (dissolved MTBE, BTEX, TBA, TPH analyses).

Selection of Analytical Methods. Table 6 lists the analytical methods used in this project. These are standard methods routinely used for similar projects.

Table 6. Analytical Methods

Measurement	Description of Analyses
Dissolved oxygen	Groundwater flow-through cell using YSI Model 85 dissolved oxygen meter.
MTBE, BTEX, TBA, TPH in groundwater	Heated headspace method: 30 ml sample warmed in 40 ml VOA vial to 35ºC followed by 0.5 ml injection of headspace onto a gas chromatograph (GC). Separation by capillary column and analysis by photo-ionization (PID) and flame-ionization (FID) detectors.
TPH in soil (only during source zone delineation)	Methanol extraction of 20-gram soil sample in a 40 ml VOA vial followed by direct injection of 2 to 10 µL of extract onto a gas chromatograph (GC). Separation by capillary column and analysis by (FID) detector.

Based on 4 years of analysis experience at this site, no matrix or environmental interferences are expected during these analyses.

Sample vials were labeled with the well ID and are then placed in a cardboard box. The sample vials are then hand-carried to the field analytical laboratory building, where the vials are placed in a water bath to bring them to a consistent temperature (approximately 50ºC). Samples are analyzed within 48 hours of collection (and usually within 24 hours).

Sample Collection. Groundwater samples were collected by ASU and NFESC personnel using slow-flow peristaltic Masterflex pumps. Each well has a dedicated polyethylene drop tube and Viton or Norprene tubing is used in the pump heads. The standard procedure is to purge the well until flow-through cell dissolved oxygen measurements stabilize and at least for one well purge volume (about 1 liter for these wells). Zero-headspace groundwater samples were collected in 40 ml VOA vials having septum caps. This procedure is identical to that used for the Equilon/ASU MTBE-biobarrier pilot test sites.

Blanks were collected by pumping deionized water through the sampling system. Replicates/ split samples and trip blanks will be collected at a frequency of 10%.

Experimental Controls. The concept of experimental controls is not applicable to this technology. Treatment effectiveness is measured by changes between up-gradient and down-gradient concentrations; some might consider the up-gradient concentrations to be control measurements.

Sample Analysis. Analysis methods are presented in Table 6. In general, each instrument is calibrated at least twice a day.

The dissolved oxygen meter calibration is a one-point calibration in air, and is standard for that instrument.

The gas chromatograph is calibrated by a three- to five-point calibration using standards that span the expected operating range. For example, standard concentrations are 10, 100, 1,000 and 10,000 μg/L-H_2O for each target analyte. At least one standard is analyzed approximately every 20 samples to identify changes in detector response or shifts in separation times.

Data Quality Parameters. Sample density for this demonstration was extremely high. There were 76 up-gradient wells, 91 cross-gradient wells, and 122 down-gradient wells used to monitor the groundwater concentration parameters. Within a single sampling event, a single individual normally took all readings for groundwater level measurements. In cases where there were multiple samplers for dissolved oxygen measurements, the meters were calibrated together to ensure similar baseline measurements. Groundwater samples taken for contaminant concentration measurements were analyzed using the field GC within 48 hours.

Data Quality Indicators. A calibration check was performed on the field equipment within every set of 20 sample measurements. For contaminant concentration analyses, duplicate samples were sent to an outside laboratory once a year as a check on the on-site laboratory.

Calibration Procedures, Quality Control Checks, and Corrective Action. The YSI dissolved oxygen meter is calibrated in air each time it is turned on in the field, per manufacturer's instructions.

All GC-FID analyses are conducted on a dedicated SRI Instruments' Model 8610C gas chromatograph using a DB-1 type capillary column. The instrument is housed in a dedicated building located approximately 200 ft from the site. The instrument is calibrated each day at three to five different concentrations spanning the concentration range of interest (e.g., 100; 1,000; and 10,000 mg/kg-soil for methanol-soil analyses and 1 to 10,000 µg/L for dissolved MTBE and BTEX concentrations). In addition, at least one calibration sample is re-analyzed approximately four times during the day to detect any instrument drift. If area counts from successive calibration analyses consistently deviate by more than 20% or if retention times vary by more than 20 minutes, then the equipment is checked for a leaking septum and a change in gas flows. If this equipment is not the source of error, then a new standard is made and analyzed. If necessary, recalibrating the entire concentration range is repeated. Reporting levels will be established based on the calibration results. Based on experience with this instrument, reporting levels of about 100 to 200 mg-TPH/kg-soil are possible for the methanol soil analysis and reporting levels of 1 to 5 µg/L are possible for the BTEX compounds and MTBE in groundwater.

3.5.8 Demobilization

The Commanding Office of NBVC has requested that the bio-barrier be signed over to them. No demobilization costs were realized. Estimated costs for demobilization are reported in Chapter 5.

3.6 SELECTION OF ANALYTICAL/TESTING METHODS

Table 6 lists the analytical methods used in this project. These are standard methods already being routinely used for similar projects.

3.7 SELECTION OF ANALYTICAL/TESTING LABORATORY

Due to the volume and sensitivity of the testing required for this demonstration, the majority of analyses were performed in the field. For the duplicate samples sent off-site, the laboratory needed to be able to measure TBA (tert-butyl alcohol) down to 50 µg/L. The laboratory selected was CAPCO Analytical Services, Ventura, California, phone (805) 644-1095 (CSDAC No. 10219, Certification No.2332).

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CHAPTER 4. PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

The general performance data are listed in Table 7.

Table 7. Performance Criteria

Performance Criteria	Description	Primary or Secondary
Contaminant Reduction	This technology degraded TBA, MTBE, and BTEX compounds to less than MCLs.	Primary
Contaminant Mobility	TBA, MTBE, and BTEX mobility was arrested by using this technology.	Primary
Hazardous Materials	No hazardous materials were generated during the course of this demonstration.	Secondary
Process Waste	No process wastes were produced.	Secondary
Factors Affecting the Performance of the Technology	Based on data gained in laboratory and field-scale pilot tests, it is known that the following factors are critical to successful application of the MTBE bio-barrier: • A well-oxygenated treatment zone (dissolved oxygen >4 mg/L). • Delivery or presence of sufficient MTBE-degrading culture to the treatment zone. • Placing the treatment zone down-gradient of residually-contaminated soils. In addition, it is anticipated that process economics will be sensitive to depth to groundwater and soil lithology.	Primary
Reliability	This demonstration did not experience any down time between Sep 2002 and Dec 2003. Potential equipment breakdowns were associated with equipment overheating (air compressor/ oxygen generator) and power supply interruptions.	Primary
Ease of Use	After the equipment was installed, the system was checked daily/weekly to ensure that the system was still on-line. A technician could perform this check. Every 6 to 12 months service is required on the oxygen generator. The person performing this task would require extra training (depending on the warranty).	Primary

Performance Criteria	Description	Primary or Secondary
Versatility	Variations on this technology might be used to treat other hydrocarbons. This demonstration focused specifically on a mixed MTBE/BTEX plume.	Secondary
Maintenance	Routine maintenance included: • Checking for leaks in the system (daily/weekly) • Changing the oil on the air compressor (every 3 months) • Servicing the oxygen generator (every 6 to 12 months)	Primary
Scale-Up Constraints	At 500 feet long, this system is 2 to 5 times the length of the average system. No scale-up constraints are foreseen.	Secondary

For the specific purposes of this experiment, a successful demonstration would be defined by the creation of a stable oxygenated zone spanning the length of the barrier, and contaminant concentrations down-gradient of the bio-barrier consistently less than the MCL for those chemicals. With respect to remedial goals, these vary by state and by local lead regulatory agency, and are often set on a site-specific basis. To date, there has been little enforcement, except in cases where potable supply wells have been impacted. In addition, revisions to state standards are still occurring. Therefore it is difficult at this time to cite any remedial goals; however, proposed drinking water standards have ranged from about 1 µg/L to about 200 µg/L Proposed values for California fall in the 0.5 to 10 µg/L range.

Remedial goals also vary in terms of the compliance location where the goal must be met and how much vertical averaging is allowed. At some sites, it may be acceptable to have concentrations measured immediately down-gradient of the bio-barrier exceed drinking water standards by a factor of 10 or 100, provided that other mechanisms (i.e., dispersion and dilution) act to further lower the concentration measured at the compliance point.

The design of this demonstration does not depend on any specific remedial goal. The system was designed based on experience to achieve the best practicable performance.

4.2 PERFORMANCE CONFIRMATION MEASUREMENTS

Remedial effectiveness was evaluated by looking at the groundwater concentration data as a series of snapshots (like those shown in Section 4.3).

Experienced personnel collected samples and analytical data. Groundwater was assessed for dissolved oxygen and target analyte (MTBE, TBA, BTEX, TPH) concentrations.

Dissolved Oxygen. Dissolved oxygen concentrations were measured using a flow-through system composed of a dissolved oxygen meter (YSI Model 55 or 85 Oxygen Probe), a flow-

through cell, and a variable-speed slow-flow peristaltic pump. Dissolved oxygen concentrations were monitored until a stable reading was obtained and until a sufficient volume of water from the well or groundwater sampling point was purged (approximately 1 liter).

Target Analytes. Groundwater samples were collected using the low-flow variable-speed peristaltic pump. After the dissolved oxygen measurement was made, a sample was collected in a 40-mL VOA vial with a septa-lined cap. Groundwater samples were analyzed in the field for MTBE, YBA, BTEX, and TPH concentrations. Samples measured in the field were analyzed using a headspace GC method. The GC used was an SRI Series 8610C or similar equipped with flame ionization (FID) and photo-ionization (PID) detectors. The GC was calibrated to known dissolved concentrations of these analytes.

All analytical equipment was calibrated or had its calibration checked several times daily when in use.

Data retained all significant digits so that round-off errors would not be propagated through the calculations. Peer checks of data recording and data reduction were used to reduce personal errors.

The quality assurance activities used in the project were used to maintain the accuracy and the precision of the system demonstration and the field analytical techniques. These activities included frequent equipment calibration, field blank samples (for shipment to the analytical laboratory), and field laboratory sample blanks. The quality assurance activities were designed to trigger corrective action activities and diagnose potential sources of error.

Precision was based on the relative percent difference (RPD) of duplicate analysis of samples. Accuracy was determined by the percentage of analyte recovered (percent recovery [%R]) from sample of known concentration. Laboratory QC consisted of analytical duplicates conducted for 10% of the total samples submitted for analysis. One laboratory control sample was included for each 20 samples to ensure that the analytical equipment was operating properly. Laboratory controls consisted of standards of known concentrations. The calculation for each of these quantitative objectives is described in the following sections.

<u>Accuracy:</u> The percent accuracy is calculated from the general equation:

$$\%\ \text{Accuracy} = \frac{100\left(X - X_a\right)}{X_a} \qquad \text{(Eq-1)}$$

where:

X = Parameter measured
X_a = Parameter's known value

The accuracy claimed by each field instrument manufacturer was compared with the percent accuracy as measured from standard samples. If the percent accuracy was less than the required accuracy, then corrective action was done.

Precision. Precision for the field laboratory analytical procedures was assessed by the analytical laboratory on an on-going basis

Completeness. Percent completeness is defined by the general equation:

$$\%\,\text{Completeness} = 100\,\frac{D_o}{D_S} \qquad \text{(Eq-2)}$$

Where:

D_o = Quantity of data obtained
D_s = Quantity of data scheduled to be obtained

The completeness objective for operations during this study was 90% for each test parameter.

Corrective action was taken whenever circumstances that threaten the generation and quality of data. The responsibility for maintaining vigilance and initiating corrective action was primarily with the system operators.

Examples of corrective actions:

Problem	Corrective Action
Analysis of standard sample indicated field GC accuracy has drifted outside established limits (calibration check) every 20 samples)	Perform replicated standard analysis Verify instrument parameters Recalibrate instrument
DO meter does not calibrate properly, or is providing suspect data.	Replace membrane Recalibrate and test again

Expected performance and performance confirmation methods are listed Table 8.

Table 8. Expected Performance and Performance Confirmation Methods

Performance Criteria	Expected Performance Metric	Performance Confirmation Method *	Actual
Primary Criteria – Qualitative			
Contaminant Reduction	Plume cut-off	Analysis of monitoring wells EM4-1 through EM4-11 (the 94 down-gradient wells)	Down-gradient samples measured > 5 µg/L MTBE, > 2 µg/L BTEX, and > 50 µg/L TBA
Contaminant Mobility	Plume cut-off	Analysis of monitoring wells EM4-1 through EM4-11 (the 94 down-gradient wells)	Down-gradient samples measured > 5 µg/L MTBE, > 2 µg/L BTEX, and > 50 µg/L TBA
Faster Remediation	Plume cut-off	Analysis of monitoring wells EM4-1 through EM4-11 (the 94 down-gradient wells)	Down-gradient samples measured > 5 µg/L MTBE, > 2 µg/L BTEX, and > 50 µg/L TBA
Ease of Use	Little training required	Experience from demonstration operation	Experience from demonstration operation
Primary Criteria – Quantitative			
Feed Stream Contaminant Concentration	0.005-20,000 µg/L MTBE, TBA, BTEX	Analysis of monitoring wells EM1-1 through EM3-25 (the 76 up-gradient wells)	Influent concentrations ranged up to 31,500 µg/L MTBE
Target Contaminant Reduction	Reduce contaminants to less than MCL	Analysis of monitoring wells EM1-1 through EM6-11	Down-gradient samples measured > 5 µg/L MTBE, > 2 µg/L BTEX, and > 50 µg/L TBA
Hazardous Materials Generated	None	Analysis for probable daughter products (TBA)	None detected
Process Waste Generated	None	Observation	None detected
Factors Affecting Performance	• Well-oxygenated treatment zone • Delivery or presence of sufficient MTBE-degrading culture to the treatment zone • Placement of the treatment zone down-gradient of residually-contaminated soils	▪ Analysis of wells A-1 through A-252 ▪ Analysis of wells EM1-1 to EM6-11 ▪ Pre-demonstration testing in the expected area	Performance well within desired range

Table 8. Expected Performance and Performance Confirmation Methods (continued)

Performance Criteria	Expected Performance Metric	Performance Confirmation Method*	Actual
Secondary Performance Criteria- Qualitative			
Plume Size	Cut off	Analysis of wells EM1-1 to EM6-11	Down-gradient samples measured > 5 µg/L MTBE, > 2 µg/L BTEX, and > 50 µg/L TBA
Reliability	No breakdowns	Record keeping	
Safety ▪ Hazards ▪ Safety Clothing	▪ Pressurized gas ▪ Safety glasses, hearing protection	Experience from demonstration operation	Experience from demonstration operation
Scale-up Constraints	None	Demonstration a full-sized, modular system	Demonstration a full-sized, modular system
Maintenance ▪ Required	▪ Compressor oil change ▪ O2 generator maintenance	Experience from demonstration operation	Experience from demonstration operation

* See J. P. Salanitro, et al., 2000.

4.3 DATA ANALYSIS, INTERPRETATION, AND EVALUATION

Due to the scale of this project, it is difficult to present results clearly. The well array is shown in Figure 7with an expanded y-axis for clarity. Every "+" indicates a pair of monitoring wells: one extending to 15 ft bgs, and one extending to 20 ft bgs.

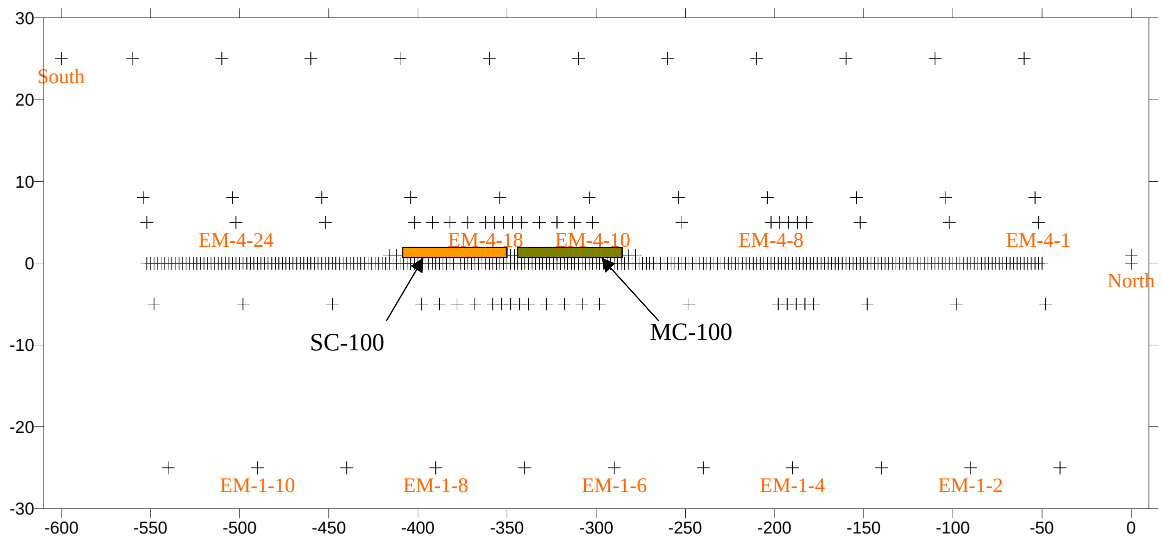

Figure 7. Enhanced plan view of the demonstration site. Locations of monitoring and gas injection wells installed in August 2000 (each "+" represents paired shallow and deep wells).

Figure 8 illustrates what the plan view looks like with a normal scale.

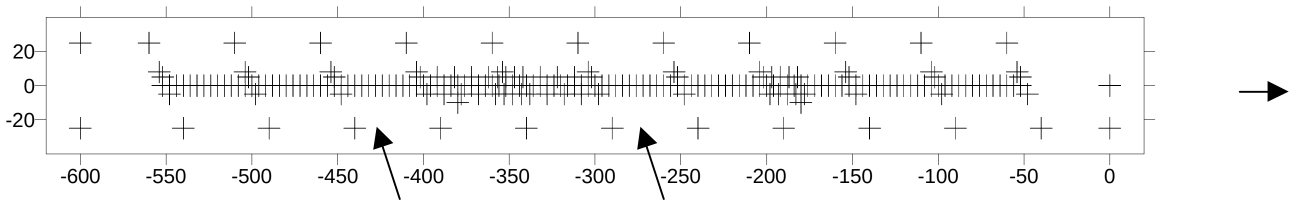

Figure 8. Actual locations of monitoring and gas injection wells installed in August 2000. Groundwater flows in the direction of the two arrows below the figure. The lateral dimensions are shown in ft from the northernmost well, and the vertical dimensions are also in ft measured from the gas injection wells row.

Performance data are presented here as a series of snapshots in time (see Figures 9, 10, 11, 12, and 13). Each contour plot represents over 225 data points (76 up-gradient, 94 down-gradient, 55 along the line of gas injection and inoculation points). For each chemical (MTBE, benzene, TBA, and oxygen) the first two contours show the state of the system before the gas injection system was turned on, the third contour shows the site conditions at the time of the bioaugmentation, the last four contours show concentration distributions at 1, 3, 10, and 15 months after bioaugmentation.

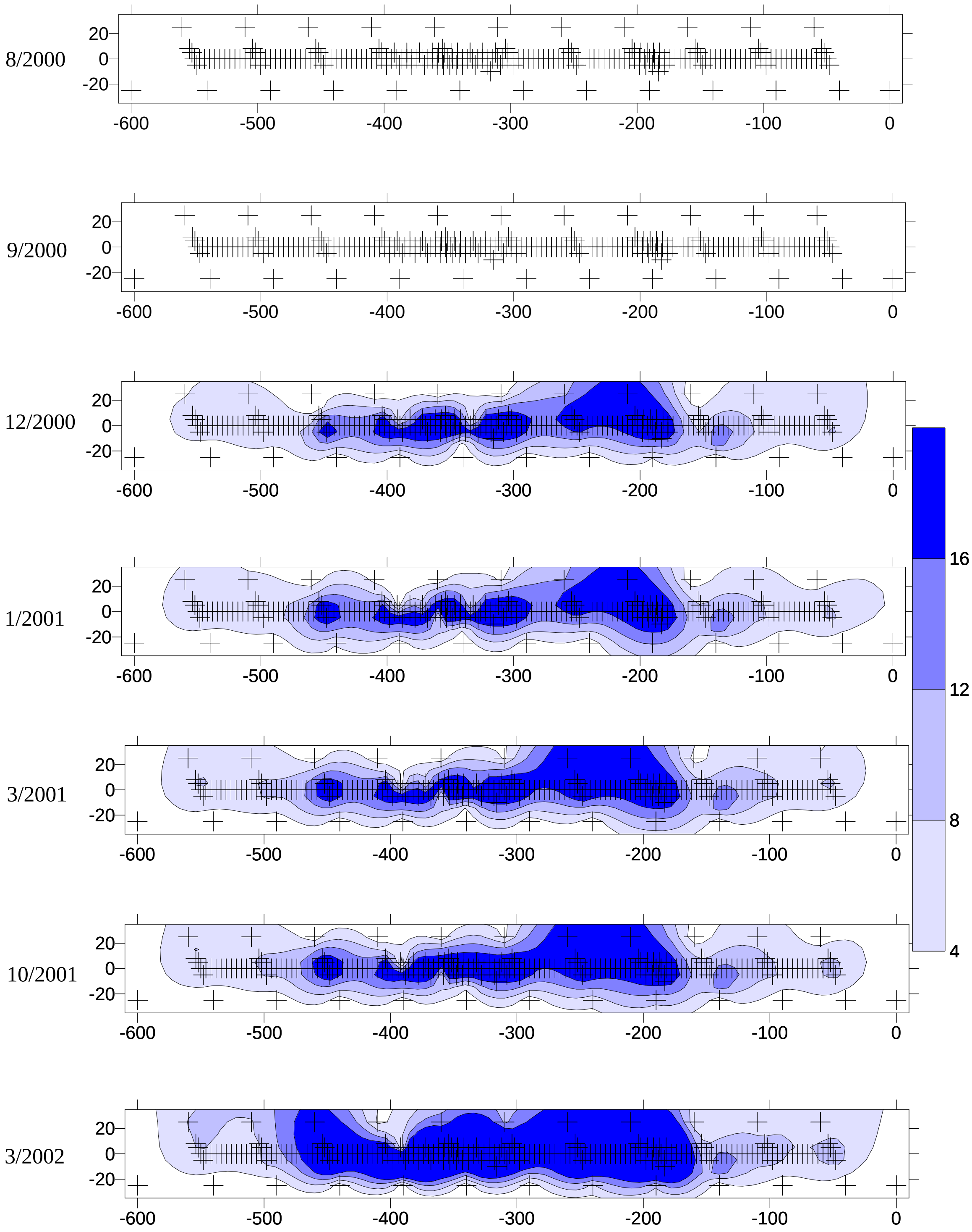

Figure 9. Dissolved oxygen time-series data (in mg-oxygen/L-groundwater); each “+” represents paired shallow and deep wells. Groundwater flows approximately from the bottom to the top of each figure.

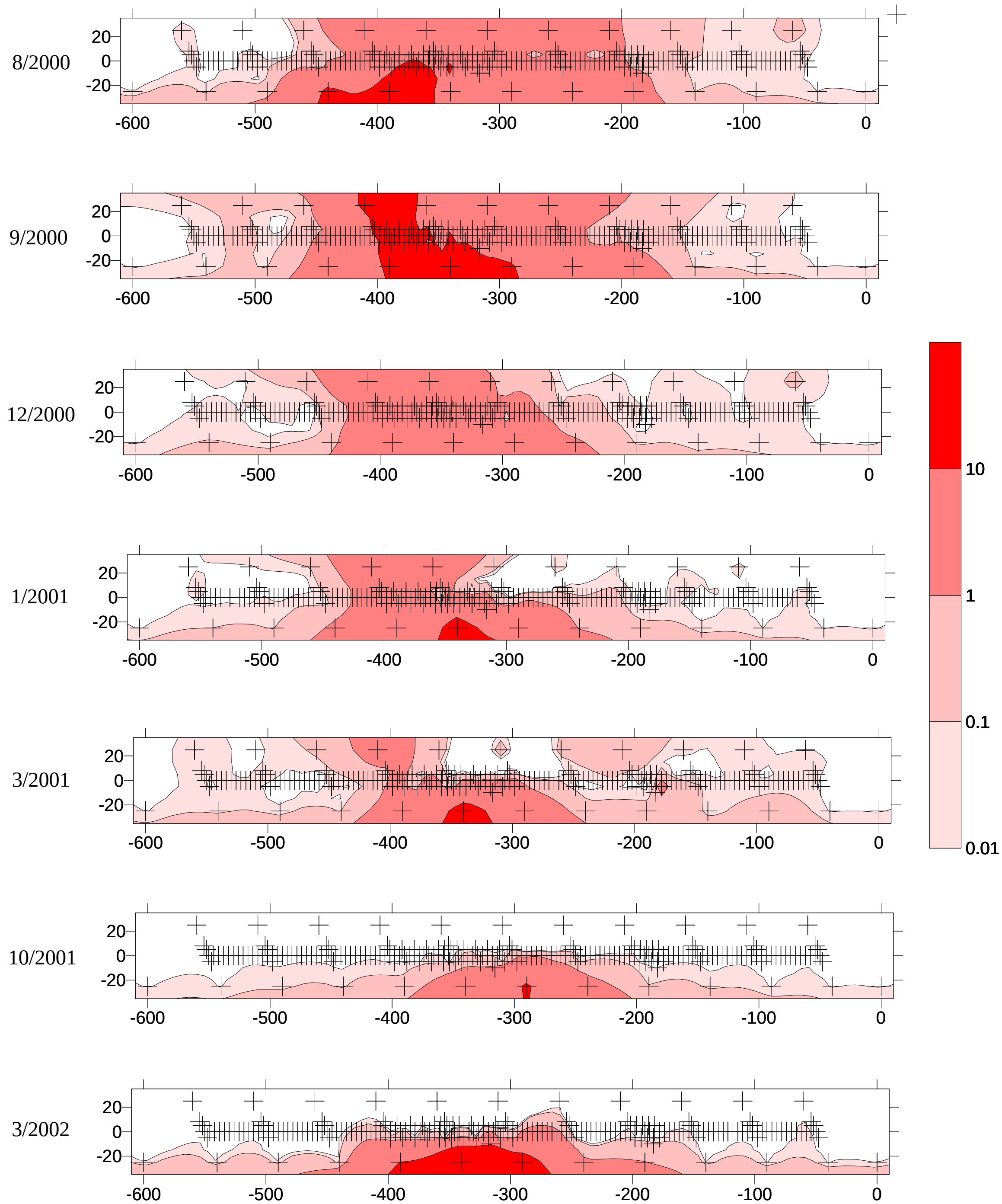

Figure 10. MTBE concentration time-series data (in mg-MTBE/L-groundwater); each "+" represents paired shallow and deep wells. Groundwater flows approximately from the bottom to the top of each figure. Lateral dimensions are shown in feet from the northernmost well, and the vertical dimensions are also in feet measured relative to the position of the row of gas injection wells.

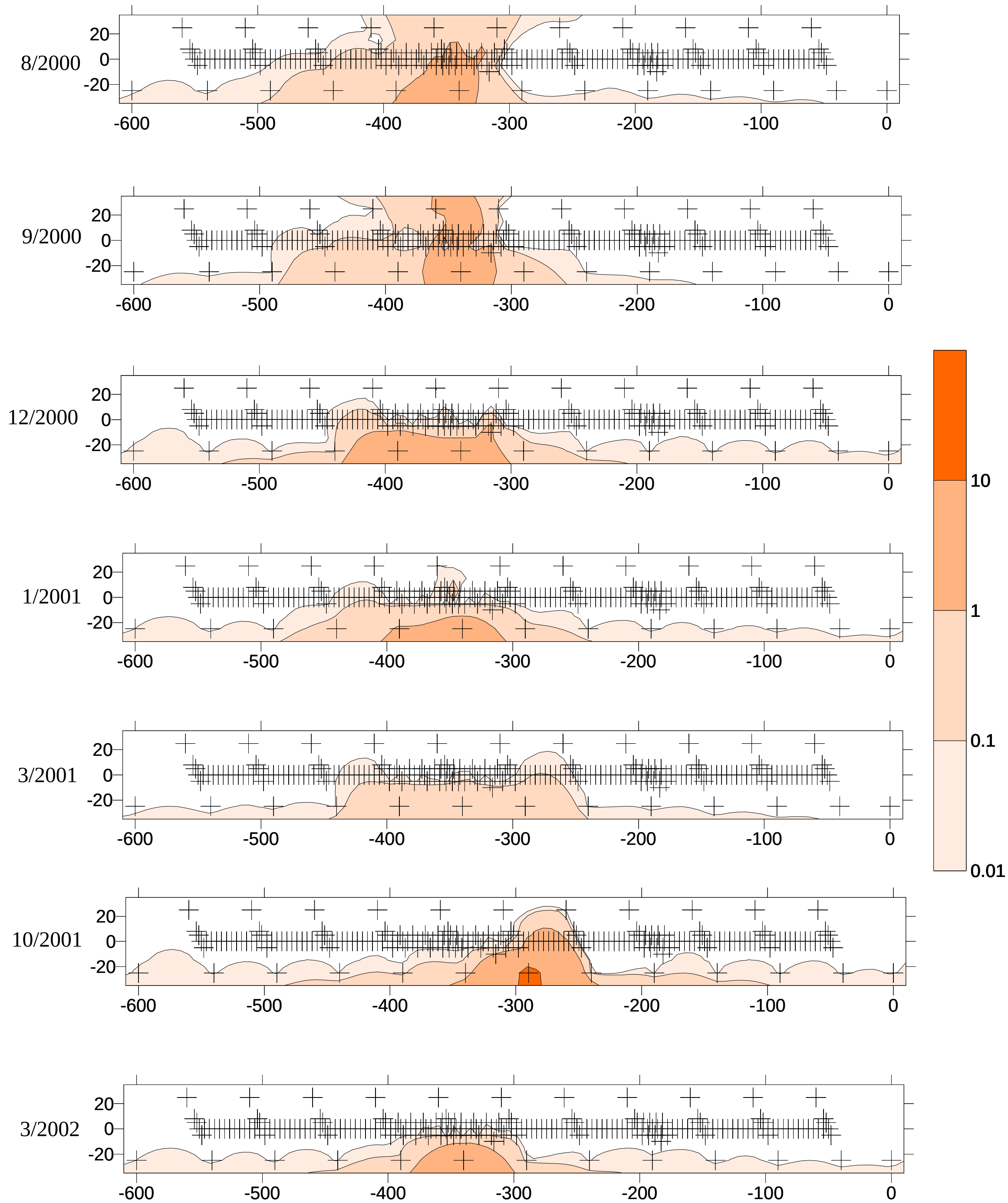

Figure 11. Benzene concentration time series data (in mg-benzene/L-groundwater); each "+" represents paired shallow and deep wells. Groundwater flows approximately from the bottom to the top of each figure. Lateral dimensions are shown in feet from the northernmost well, and the vertical dimensions are also in feet measured relative to the position of the row of gas injection wells.

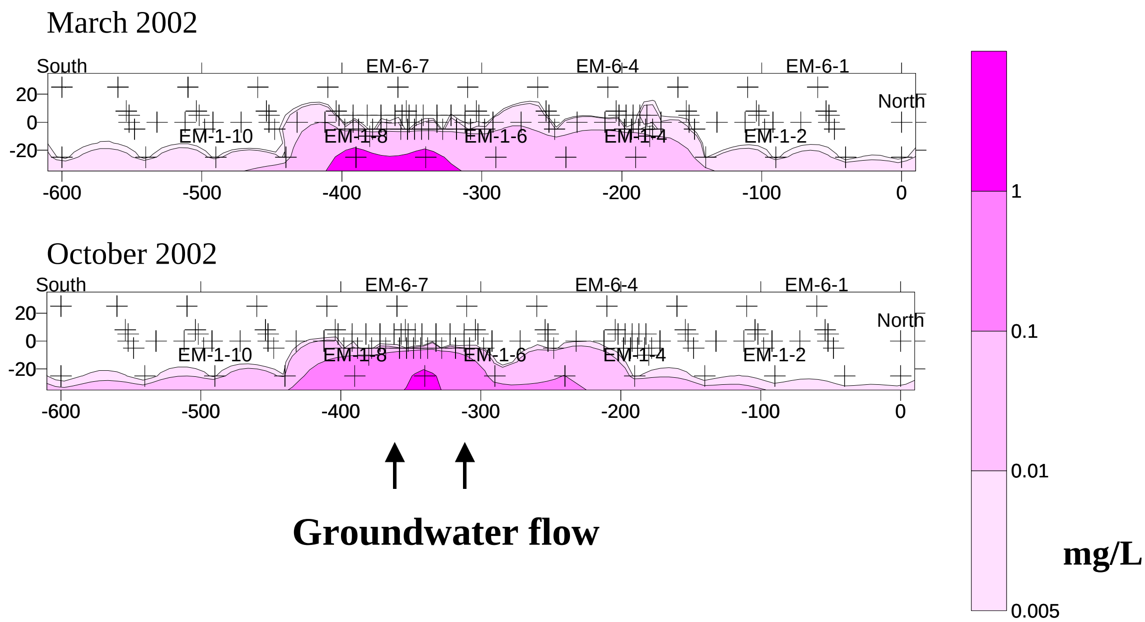

Figure 12. TBA concentration distribution from March 2002; each "+" represents paired shallow and deep wells. Groundwater flows approximately from the bottom to the top of each figure. Lateral dimensions are shown in feet from the northernmost well, and the vertical dimensions are also in feet measured relative to the position of the row of gas injection wells.

Overall system performance, as indicated by comparing groundwater concentration data to baseline concentration data, showed:

- The aeration/oxygenation system was sufficient for the demonstration. Site-wide dissolved oxygen concentrations were below 1 mg-oxygen/L-groundwater before the system was turned on. Afterwards, all wells within 5 feet of the gas injection row showed groundwater oxygen levels above 4 mg-oxygen/L-groundwater (the level necessary to stimulate and support aerobic degradation).

- Groundwater contaminant concentrations leaving the barrier were less than the detection limit after 7 months.

- Groundwater contaminant concentrations did not increase in the wells to the north and south of the barrier, indicating that the contamination was not circumventing the barrier.

Aeration/oxygenation began on September 22, 2000. Measured dissolved oxygen data (Figure 9) showed the gas-injection system to be robust and capable of elevating the dissolved oxygen above 4 mg-oxygen/L-groundwater (the target level for aerobic biodegradation). Levels above 12 mg/L were achieved by the oxygen gas injection, and levels ranging from 4 to 8 mg/L were achieved by air injection sections of the system.

Measured down-gradient MTBE concentrations declined 1to 3 months after bioaugmentation (and 4 to 6 months after gas injection started). MTBE concentrations in groundwater exiting the treatment system were below detection limits within 7 months (Figure 10).

The dissolved benzene concentration distributions (Figure 11) show a faster response than the MTBE concentrations. Down-gradient benzene concentrations show noticeable decreases within 3 months of the initiation of the air injection system. Since December 2000 benzene concentrations immediately down-gradient were below detection limits.

TBA concentrations measured in March and October 2002 show a similar degree of treatment as MTBE and BTEX.

The combination of hydraulic data (Figure 13) and the contaminant concentration distributions demonstrates that no significant bypassing of contaminants occurred during this test.

The spreadsheets contain data files with the results of the aquifer characterization/specific capacity tests, water level measurements, dissolved oxygen concentrations, and target analyte concentrations.

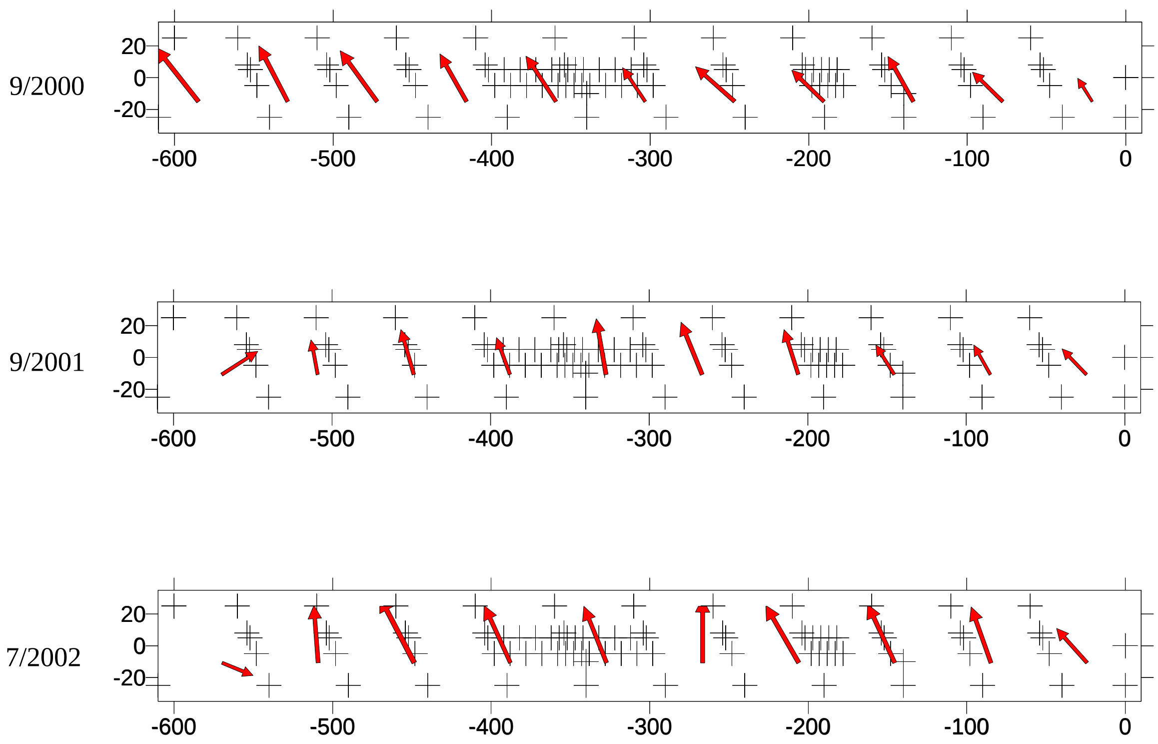

Figure 13. Flow directions inferred from groundwater elevation contours from (a) before gas injection, (b) after 1 year of operation, and (c) after 1 year, 10 months of operation. Water levels in the left-hand portion of the barrier often showed the effect of irrigation on the grassy area to the south of the biobarrier.

The performance of this system can be evaluated by answering the following questions:

- Is the zone of aeration/oxygenation stable and does it span the width of the contaminant plume?

- Does influent groundwater flow through the biobarrier or around it?

- Are contaminant concentration reduced as groundwater flows through the treatment zone?

- Are the contaminant reductions sustainable?

The presence and stability of the zone of aeration/oxygenation is assessed by inspecting the dissolved oxygen concentration distributions. Groundwater oxygen concentrations above 4 mg-oxygen/ L-groundwater are required for this demonstration.

Contoured water level measurements coupled with contaminant concentrations in groundwater at the perimeter wells provide insight as to whether the groundwater is going through or around the system.

Concentration distribution plots illustrate the desired level of contaminant degradation achieved and the time sequence provides evidence of treatment stability/consistency.

The current accepted remedial technology for MTBE treatment is pump and treat (P&T). P&T systems require contaminated water to be pumped to the surface, processed through an aboveground treatment system (often GAC), and then the treated water has to be disposed of (it is often difficult to get permission to re-inject the treated water on site). This creates potential new waste streams and depletes the reservoir of available groundwater. In comparison, the bio-barrier technology treats the contaminant in place, mineralizing the MTBE into water and carbon dioxide.

P&T has the advantage of immediately containing an advancing plume, whereas a bio-barrier system may need a few months to establish its degradation potential. Once the organisms have acclimated, however, treatment is robust.

In comparison with conventional P&T systems, the bio-barrier technology is less expensive to install and has lower long-term operation and maintenance costs. At Port Hueneme, an interim full-scale pump and treat system was installed and operated at the down-gradient edge of the dissolved MTBE plume. The FY02 O&M costs for maintaining the Port Hueneme P&T system are $250K/year compared to the biobarrier O&M costs of $75K/year.

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CHAPTER 5. COST ASSESSMENT

This chapter discusses the cost considerations involved in the application of the bio-barrier technology to an MTBE plume. Cost reporting for the full-scale bio-barrier demonstration, a cost analysis and a cost comparison are discussed.

5.1 COST REPORTING

The site at Port Hueneme is a gasoline-contaminated site located at the edge of the source zone. Groundwater is located at approximately 7 to 9 feet bgs, with the contaminated portion of the aquifer located from the groundwater table down to approximately 20 feet bgs. The bio-barrier demonstration spans the full width of the Port Hueneme dissolved MTBE plume. At 500 feet wide, this site is several times larger than a typical MTBE plume. Table 9 details the costs for the Port Hueneme site.

Table 9. Cost Tracking

Cost Category	Sub Category	Cost ($)
Start Up	Site Characterization	4,040.00
Capital Costs	Oxygen Generator	65,344.00
	Modifications	
	Fence	19,208.00
	Buildings	29,716.00
	Installation	
	Wells	66,890.00
	Piping	35,078.00
Operating Costs	Supervision	21,100.00
	Operator Labor	74,239.00
	Operator Training	3,165.00
	Maintenance	19,880.00
	Utilities	10,419.00
	Consumables	10,678.00
	Raw Materials - microbes	90,964.00
	Sampling and Analysis	44,400.00
	Long Term Monitoring	---
Demobilization	Electrical Removal	570.00
	Piping/Tank Removal	1,880.00
	Well Decommission	27,800.00
	Fence Removal	2,950.00
	Asphalt Repair	31,000.00

With the exception of the well installation and electrical installation, ASU and NFESC personnel installed the bio-barrier at Port Hueneme in 5 weeks. Table 10 lists the actual installation costs. The bio-barrier installation costs were $307K, at a cost of $614/linear foot.

Table 10. Port Hueneme Bio-Barrier Installation Costs
(500-foot wide system)

Bio-Barrier Installation	Materials ($)	Labor ($)	Total ($)
Air and O_2 Delivery System	96,917	89,603	186,519
Field Laboratory	18,239	11,477	29,716
Culture Injection	48,758	42,206	90,964
Total	**$163,914**	**$143,286**	**$307,200**

A detailed cost breakdown of the installation costs was done. The main components of the biobarrier system are the injection/monitoring wells, the injection of the culture and the air and oxygen delivery system.

- Vironex, a drilling company using direct push Geoprobe™ technology, installed 426 wells in 1 week. Working 10-hour days, and sometimes with two rigs and two crews, the crews installed an average of 47 wells each day.

- During the culture injection phase, Vironex was able to inject culture across 24 linear feet in a day. Injections were spaced 1 foot horizontally and 1 foot vertically from 10 to 20 feet bgs.

- The oxygen generator cost $48K with air and oxygen delivery, the total cost was $187K. In order to save project funds, the oxygen delivery system at Port Hueneme was installed aboveground (main header lines between the biobarrier and oxygen generator were installed in a trench). Depending on site requirements, an oxygen delivery system could be installed almost completely below ground. At Port Hueneme, it was estimated that it would cost an additional $170/foot to install the oxygen delivery system underground.

- A small field laboratory was installed at Port Hueneme to conduct the on-site analysis at a cost of $30K.

During the 2-year demonstration, NFESC and ASU personnel operated and maintained the bio-barrier. The annual O&M costs for the biobarrier averaged $77K a year as shown in Table 11. The oxygen generator compressor failed after 18 months of operation because it was a 220-volt compressor and the power on the Base was 208 volts.

Table 11. Port Hueneme Bio-Barrier Annual Operation and Maintenance Costs (500-foot wide system)

Bio-Barrier Annual O&M	Materials ($)	Labor ($)	Total ($)
Oxygen Generator O&M	5,460	13,540	19,000
Sampling and Analysis	0	44,400	44,400
Utilities	0	14,443	14,443
Total	**$5,460**	**$72,383**	**$77,843**

5.2 COST ANALYSIS

Based on the full-scale demonstration costs at Port Hueneme and input from Shell Global Solutions (US) Inc., the projected costs to install a bio-barrier at a site range from $800/linear foot to $1,050/linear foot for aquifers less than 30 feet bgs as shown in Table 12. The well installation costs will increase for aquifers greater than 30 feet bgs because the efficiency of direct push technology is reduced, and at some depths conventional drilling and installation techniques would be required. In the spreadsheet, the projected future length of the bio-barrier system can be adjusted to provide cost estimates for different plume widths. The major factors affecting costs associated with the implementation of a biobarrier technology are:

- Soil characteristics (costs increase for finer-grained soils)
- Need for bioaugmentation or sufficiency of biostimulation
- Depth to ground water (costs increase with depth)
- Width of the plume (costs increase as the treatment width increases)
- Type of installation required at the site (i.e., aboveground or underground)

Table 12. Future Bio-Barrier Systems Installation Costs (500-foot wide system)

Bio-Barrier Installation	Materials ($)	Labor ($)	Total ($)
Air & O_2 Delivery System	90,160	79,182	169,342
Field Laboratory	N/A	N/A	N/A
Culture Injection	307,650	76,103	383,753
Total	**$397,810**	**$155,286**	**$553,096**

The operation and maintenance costs for a future bio-barrier system are similar to the requirements of the Port Hueneme bio-barrier as shown in Table 13. The oxygen generator should be checked 2 or 3 times a week. The compressor usually runs 8 to 10 hours a day. The utility cost used in these calculations was $0.14/kWh.

Table 13. Future Bio-Barrier Systems Operation and Maintenance Costs
(500-foot wide system)

Bio-Barrier Annual O&M	Materials ($)	Labor ($)	Total ($)
Oxygen Generator O&M	4,460	12,980	17,440
Sampling and Analysis	0	44,000	44,000
Utilities	0	14,083	14,083
Total	**$4,460**	**$71,063**	**$75,523**

5.3 COST COMPARISON TO CONVENTIONAL TECHNOLOGIES

In comparison with conventional pump and treat systems, the bio-barrier technology is both less expensive to install and has lower long-term operation and maintenance costs. At Port Hueneme, an interim full-scale pump and treat system was installed and operated at the down-gradient edge of the dissolved MTBE plume. The FY02 O&M costs for maintaining the Port Hueneme P&T system are $250K/year compared to the bio-barrier O&M costs of $75K/year. For the Port Hueneme site, several different treatment options, shown in Table 14, were evaluated for the final remedy of the MTBE plume.

The Navy published a pump and preat evaluation study in 2001 (Battelle, 2001). The Navy is currently operating 24 P&T systems. Some of pump and treat system statistics from the review were:

- 79% were installed before 1999
- 79% were designed to operate for more than 5 years
- 66% were designed to operate for more than 10 years
- 58% were designed as ground water treatment systems
- 46% were designed as a interim action
- 82% conduct ground water monitoring annually
    - 46% conduct ground water monitoring semi annually
    - 36% conduct ground water monitoring quarterly
- 46% of the systems are operating at less than 75% design flow
- The construction costs for the 24 systems was $61M
- The current O&M costs for the 24 systems is $10M/year

Table 14. Final Remedy Options for the NBVC MTBE Plume

Option	FY02 O&M Costs	Life Cycle O&M Costs/ Service Life	Advantages	Issues
Option 1: Continue to operate the pump and treat system. Remove the bio-barrier in Dec 02 at the end of the ESTCP demonstration.	\$250K	\$54 million/ 240 years	Control and containment system is located at leading edge of plume thereby preventing further migration of the plume. Acceptable to LARWQCB as interim remedy.	High O&M costs/extended service life. Costs increase if GAC treatment is necessary. Disposes 1 million gallons of untreated water to sanitary sewer annually. Estimated time of 200 years for pump and treat system to capture 200-gallon MTBE mass between the system and the biobarrier, based on 3 years of monitoring data from biobarrier demonstrations. Cleanup cost per gallon of MTBE is \$270K. Removal of biobarrier will result in MTBE contaminated water flowing again from source zone. Removal of biobarrier creates a migration risk from future spills.
Option 2: Continue to operate the bio-barrier. Turn off the MTBE interim plume control and containment cystem.	\$75K	\$3 million/ 40 years	Low O&M costs; shorter service life. Saves 10 million gallons of groundwater annually. Cuts off source zone contamination; protects against future spills Complete mineralization of MTBE to CO_2 and water.	Estimated mass of 200 gallons of MTBE will continue down-gradient migration. Levine-Fricke (LFR) evaluated the plume migration using the groundwater flow model. If predicts MTBE may discharge into surface waters in concentrations in the 1,300 µg/L range, exceeding LARWQCB proposed discharge standard of 5 ppb. Eco-risk of MTBE to marine environment does not exceed acute (54 mg/L) or chronic (18 mg/L) aquatic criteria. Will require acceptance by LARWQCB.

Table 14. Final Remedy Options for the NBVC MTBE Plume (continued)

Option	FY02 O&M Costs	Life Cycle O&M Costs/ Service Life	Advantages	Issues
Option 3: Continue to operate the bio-barrier. Convert the pump and treat system to an air injection only bio-barrier.	$125K for first 40 years; $75K for remaining 200 years.	$20 million/ 240 years	Will contain both main source and leading edge of plume. Protects against future spills. No groundwater or other disposal costs. Low capital and O&M costs. Complete mineralization of MTBE at both locations to CO_2 and water.	Bio-barrier studies conducted at Port Hueneme demonstrated that naturally occurring MTBE degraders are stimulated by adding or air or oxygen. Converting pump and treat system to air bio-barrier will cost $300K. Will require LARWQCB acceptance.

CHAPTER 6. IMPLEMENTATION ISSUES

6.1 ENVIRONMENTAL CHECKLIST

Permitting issues endemic to this technology involve those associated with well drilling and waste disposal. Air and oxygen injection are not normally permitted.

6.2 OTHER REGULATORY ISSUES

For bioaugmentation projects, microbe injection should be discussed with regulators during the design phase. For the Port Hueneme MTBE plume, the Los Angeles Regional Water Quality Control Board accepted the bio-barrier technology as the final remedy for the MTBE plume.

6.3 END-USER ISSUES

This issue is of interest to the EPA, state regulatory agencies, and to the gasoline refining and marketing industry, all of which are desperately seeking practical solutions to this problem. The treatment of MTBE-impacted sites is of interest to DOD as gasoline is stored, transported, or dispensed at many military installations. The management and treatment of MTBE-impacted aquifers is of particular importance to DOD. In recent years, DOD has encouraged and demonstrated the use of in situ natural attenuation for the management of dissolved BTEX groundwater plumes at fuel spill sites. Until recently, this approach had been gaining acceptance in the regulatory community; however, with the increased awareness of MTBE and its potential to cause much more extensive impacts than BTEX, the acceptability of natural attenuation for sites containing MTBE is now being questioned by regulators. Without other practicable alternatives to P&T at MTBE-impacted groundwater, the use and acceptance of natural attenuation as a remediation/aquifer management option may become limited in the near future.

Procurement issues are minimal; most of the equipment used in this demonstration came off the shelf. Of the materials used, the oxygen generator was the most likely to be custom-built for a particular job. The microorganisms were from a commercial branch of Shell Global Solutions Technology Center.

This technology is effective in a shallow, homogeneous aquifer. The next logical step is to establish its effectiveness and economics in a deeper, heterogeneous setting.

It appears that biostimulation (aeration only) could be a viable option at many sites. In this demonstration, biostimulation was successful for treatment zones where the influent MTBE concentration was as great as 100 to 1,000 µg/L. It is not known if biostimulation would provide sufficient treatment for higher concentrations or fluxes. It is also not known how variable the performance of biostimulation might be from site to site.

At the demonstration site, concentrations >1,000 µg/L passed through the bioaugmented zone. The data clearly show significant treatment to non-detect levels with no apparent decline in activity during the lifetime of this test.

The presence of BTEX did **not** inhibit the degradation of MTBE.

Although Schedule 40 PVC is easy to work with, it is not designed to carry air or oxygen under pressure unless it is buried. For the Port Hueneme bio-barrier system, polyethelyne tubing carries the air/oxygen from the buried PVC lines to the bio-barrier tanks. Depending on the service life required, other materials such as stainless steel tubing could be used. It is also important not to restrict the diameter of the air lines from the satellite storage tanks to the injection wells, as the high-pressure, short-duration flow to the wells is critical.

The oxygen generators are purchased as a turn-key system. It is important to check the power coming into the site before ordering the oxygen generator system. On a military base, 208 volts is common which can cause problems if the oxygen generator compressor is designed for 220 volts.

CHAPTER 7. REFERENCES

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APPENDIX A

QUALITY ASSURANCE PROJECT PLAN

In Situ Bioremediation of MTBE in Groundwater

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INTRODUCTION

This Quality Assurance Project Plan (QAPP) establishes the quality assurance guidelines to be used during the "In Situ Bioremediation of MTBE in Groundwater" project. This QAPP was developed to address the DOD requirements for precision, accuracy, completeness, and comparability of data collected and generated during this demonstration. The QAPP also provides the quality assurance requirements for data handling, manipulation, and reporting. It was designed to ensure the quality of the data gathered and generated, as well as the conclusions and recommendations reached from the use of the data.

PROJECT OBJECTIVES

The objective of this demonstration is to evaluate and implement an innovative technology that is designed to contain dissolved MTBE groundwater plumes. In this technology, a biologically reactive groundwater flow-through barrier (the "bio-barrier") was established down-gradient of a gasoline-spill source zone. Groundwater containing dissolved MTBE flows to, and through, the bio-barrier. As the MTBE passes through the bio-barrier, it is converted by microorganisms to innocuous by-products (carbon dioxide and water). Groundwater leaving the down-gradient edge of the treatment zone contains MTBE at concentrations less than or equal to the treatment target levels. Specific objectives include the following.

- Install and operate a full-scale MTBE biobarrier across a mixed BTEX/MTBE dissolved plume, with sections of the biobarrier corresponding to different possible design configurations. At a minimum, design configurations to be tested include a zone seeded with MTBE-degrading organisms and aerated with oxygen gas (bio-augmented), and a zone not seeded with any organisms, but aerated with oxygen gas (biostimulated).

- Assess the reductions in MTBE, BTEX, and TPH concentrations achieved by the biobarrier with time.

- Assess the effectiveness of oxygen delivery to the target treatment zone.

- Collect information needed for an economic assessment of the technology.

- Make information available on the progress of the project available through a dedicated WWW-site.

- Prepare a technology implementation manual and economic cost model for the technology.

The critical measurements are focused on assessing groundwater quality (contaminant concentrations and dissolved oxygen) and system hydraulics. These are discussed below.

EXPERIMENTAL DESIGN

The following section describes measurements to be made during this project; these are divided into categories focused on water quality changes and system hydraulic measurements.

Groundwater Quality Measurement

Groundwater will be assessed for dissolved oxygen and target analyte (MTBE, TBA, BTEX, TPH) concentrations.

Dissolved Oxygen. Dissolved oxygen concentrations will be measured using a flow-through system composed of a dissolved oxygen meter (YSI Model 85 Oxygen Probe or similar), a flow-through cell, and a variable-speed slow-flow peristaltic pump. Dissolved oxygen concentrations will be monitored until a stable reading is obtained and until a sufficient volume of water from the well or groundwater sampling point is purged (approximately 1 liter for the proposed wells).

Target Analytes. Groundwater samples will be collected using the low-flow variable-speed peristaltic pump discussed above, and after the dissolved oxygen measurement is made, a sample will be collected 40-mL VOA vial with a septa-lined cap. Groundwater samples will be analyzed in the field for MTBE, YBA, BTEX, and TPH concentrations. Samples measured in the field will be analyzed using a headspace gas chromatography (GC) method. The GC used will be an SRI Series 8610C or similar equipped with flame ionization (FID) and photoionization (PID) detectors. The GC will be calibrated to known dissolved concentrations of these analytes.

System Hydraulics Measurements

The following measurements relate to better understanding the groundwater flow system, and any changes to it caused by installation and operation of the bio-barrier.

Depth to Groundwater. : The depth to groundwater will be measured with a standard electronic interface probe. For example, typical devices are comprised of an electronic sensor attached to the end of a 50- to 200-foot measuring tape marked with 0.01-foot increments.

Hydraulic Conductivity Measurements. Micro-well continuous pump tests will be conducted as follows: (a) an interface probe will locate the static water level in a small-diameter well, (b) tubing will be lowered so that the tubing intake is located a known distance below the static water level, (c) a peristaltic pump will be operated at full speed with the hope that the pump rate is faster than the recharge rate to the well, so that the draw-down becomes the depth to the tubing intake, (d) the flow rate is measured by the standard bucket-and-stopwatch approach, and (e) the data is analyzed to determine hydraulic conductivity.

Visual Dye Tracer Measurements. A visual dye will be injected in up-gradient groundwater monitoring wells and will be monitored through sampling the proposed monitoring well network. The dye is readily visible over a wide range of concentrations, so the reporting

will be qualitative (e.g., “no color,” “light green color,” “dark green”). The dye will be used to assess travel times to various points in the system.

PROJECT ORGANIZATION AND RESPONSIBILITIES OF KEY PERSONNEL

The Navy point-of-contact is Ms. Karen Miller. The Arizona State University points-of-contact are Dr. Paul Johnson and Dr. Cristin Bruce.

DATA QUALITY OBJECTIVES

Arizona State University (ASU) will conduct the analysis of groundwater samples in the field with a laboratory quality GC (SRI Model 3610C or equivalent). The ASU field laboratory will establish data quality objectives similar to those outlined below.

The quality assurance activities in this project will be used to maintain the accuracy and the precision of the system demonstration and the field analytical techniques. These activities include frequent equipment calibration, field blank samples (for shipment to the analytical laboratory), and field laboratory sample blanks. The quality assurance activities are designed to trigger corrective action activities and diagnose potential sources of error.

ASU will be responsible for summarizing the laboratory data and for data reduction and technology evaluation. Dr. Paul Johnson will be responsible for reviewing analytical data, identifying any deviations from the established protocols and data quality objectives, and then deciding how the data will be used, and what corrections, if any, need to be made to the field analytical procedures.

Precision will be based on the relative percent difference (RPD) of duplicate analysis of samples. Accuracy will be determined by the percentage of analyte recovered (percent recovery [%R]) from sample of known concentration. Laboratory QC will consist of analytical duplicates conducted for 10% of the total samples submitted for analysis. One laboratory control sample will be included for each 20 samples to ensure that the analytical equipment is operating properly. Laboratory controls will consist of standards of known concentrations. The calculation for each of these quantitative objectives is described in the following sections.

Accuracy. The percent accuracy is calculated from the general equation:

$$\% \text{ Accuracy} = \frac{100\left(X - X_a\right)}{X_a} \qquad \text{(A-1)}$$

where: X = the parameter measured
X_a = the parameter's known value

The accuracy claimed by each field instrument manufacturer will be compared with the percent accuracy as measured from standard samples. If the percent accuracy is less than the required accuracy then corrective action will be initiated.

Precision. Precision for the field laboratory analytical procedures will be assessed by the analytical laboratory on an on-going basis. Dr. Johnson will review all analytical data to ensure that any questions concerning data validity are addressed at the earliest time possible.

Completeness. Percent completeness is defined by the general equation:

$$\% \text{ Completeness} = 100 \frac{D_o}{D_S} \qquad \text{(A-2)}$$

Where: D_o = quantity of data obtained
D_s = quantity of data scheduled to be obtained

Completeness in meeting the scheduled data recovery objectives will increase throughout the project as the experience base in equipment operation characteristics increases. The completeness objective for operations during this study is 90% for each test parameter.

CORRECTIVE ACTIONS

Corrective action will be taken whenever circumstances arise that threaten the generation and quality of data. Much time and effort will be invested in designing and starting up the bio-barrier and there is need to operate this system over a long period of time; therefore, extreme vigilance in recognizing the need for corrective action is critical. The responsibility for maintaining vigilance and initiating corrective action will be the system operators. Corrective action, however, may be initiated by the Project Officer.

The specific nature of all corrective actions and the operating limits that would trigger the need for corrective action for all aspects of the remediation system and analytical operations are to numerous to anticipate. Most corrective actions will be empirical in nature as the following specific examples show.

<u>Problem</u>	<u>Corrective Action</u>
Analysis of standard sample indicated field GC accuracy has drifted outside established limits (calibration check every 20 samples).	Perform replicate standard analysis. Verify instrument's parameters. Recalibrate instrument.
DO meter does not calibrate properly, or is providing suspect data.	Replace membrane Recalibrate and re-test

DATA COLLECTION

Sampling Frequency

Sampling frequency is given in Table A-1.

Table A-1. Performance Measurements and Sampling Frequency

Measurement	Purpose	Frequency
Visual inspection	Verification of system operation - track system down-time	Daily
Record of timer sequences and operating pressures	Track operating conditions	Whenever changes are made to the timer sequence or operating pressure.
Groundwater sampling – dissolved oxygen	Assess performance of the oxygen delivery system	Monthly (initially), then every 2 months after 3 months of operation.
Groundwater sampling – MTBE, BTEX, TBA, TPH analyses	Assess performance of the biobarrier	Monthly (initially), then every 2 months after 3 months of operation.
Groundwater elevations	Track changes in groundwater levels	Monthly (initially), then every 2 months after 3 months of operation.
Tracer Test	Assess groundwater flow relative to initial conditions	Once after 3 months of system operation.

Sample Collection Techniques

Samples will be collected in a manner consistent with the sample matrix and the parameters being analyzed. Groundwater or soil gas samples will be collected.

Groundwater samples will be collected using a variable-speed low-flow peristaltic pump and collected in a 40-mL VOA vial with a septa-lined cap. Analyses will be conducted in the field within 48 hours.

All sample collection devices will be cleaned and prepared in accordance to applicable EPA procedures before each use.

Sample Identification Procedures

Each sample will be identified with a unique sample number coded to correlate to the sampling location and assigned by the sample collector at the time of collection. This code will be logged into a master field data sheet indicating who collected the sample, where the sample was collected, and the date of sample collection.

Each sample will be logged in the project record book (see section on Documentation) with the information recorded on the label and a brief description. Any samples being shipped off-site for analysis will be logged on a chain-of-custody log sheet to be sent with the samples to document sample receipt.

DOCUMENTATION AND RECORD KEEPING

A chronological record on the installation and operation of the MTBE bio-barrier will be maintained in the project record books. The record books will be used to record events pertaining to systems operation, including sampling, changes in process conditions (flow and temperature), preventative maintenance, equipment failures, corrective actions, operators' initials, and the date. The project record book will be reviewed, initialed, and dated on a regular basis by the project officer or project researcher.

Quality assurance will be implemented throughout this study through planning, control, and assessment.

Quality planning for this project includes the preparation of this QAPP.

Each field analytical instrument will be calibrated daily before using, and as needed as determined by calibration checks.

DATA REDUCTION, VALIDATION, AND REPORTING

Data Reduction

ASU researchers and technicians will be responsible for data reduction, as required to make adjustments to the remediation system. Changes in system configuration may be made to optimize system operation. Data will retain all significant digits so that round-off errors will not be propagated through the calculations. Peer checks of data recording and data reduction will be used to reduce personal errors.

Data Validation

Data validation will be conducted by process operators and will consist of comparing the data against standard curves and control limits for each analyte. Control limits and standard curves for each field analytical method and analyte will be set as described in the operation manual for each field instrument.

Data Reporting

The final report will be submitted to the DOD Project Officer. This report will include analytical data, the results of the QA/QC activities, and a summary of the operational characteristics of the air sparging system.

PERFORMANCE AND SYSTEM AUDITS

Performance and system audits primarily apply to the field instrumentation that will be used. Calibration of instruments (or calibration checks, depending on the instrument) will be conducted daily or whenever the instrument is turned on for use.

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APPENDIX B

NETTS PORT HUENEME HEALTH AND SAFETY PLAN

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INTRODUCTION

The Naval Construction Battalion Center (NCBC), Port Hueneme, California, has a National Test Location (NTL) for advanced characterization and remediation technologies demonstrations. Port Hueneme is bordered on the west by the Pacific Ocean and on the east by the cities of Oxnard and Port Hueneme in Ventura County.

The Naval Facilities Engineering Service Center (NFESC), a tenant command on NCBC, will manage NTL sites for both in-situ and ex-situ characterization and remedial technology demonstrations. The technology demonstrations will be performed by various Federal, Government, academia, and private industry groups.

ENVIRONMENTAL SITES AND CONTAMINANT HISTORY

Navy bases have generated petroleum hydrocarbon-contaminated soil from fuel delivery systems leaks and during removal of underground storage tanks (USTs). Soils contaminated with various types of fuel hydrocarbons have been stockpiled at the NTL treatment facility for use in demonstrations of ex-situ biodegradation, physical and chemical destruction, or monitoring of petroleum hydrocarbons and hazardous compounds. A list of contaminants that may be characterized or treated is listed in Table B-1. Throughout the rest of this document, the term hazardous compounds will be used as a collective term for the compounds and waste material listed in Table B-1.

An ex-situ treatment facility was constructed in the north-central portion of CBC, in the area of 23rd Avenue, Track 14 Road, and Minersville Road (Figure B-1). The facility covers approximately 3.8 acres, and is paved with asphalt. Approximately 1,500 cubic yards of contaminated soil at any one time will be stockpiled and treated by various types of advanced remediation technologies.

The treatment area is surrounded by a 6-inch high asphalt berm. A grounded 6-foot high security chain-link fence provides site security. The treatment area can be accessed through only one gate, which is continually monitored when open and is locked at all other times. The treatment area surface slopes gently from the northeast to the southwest corner of the ex-situ treatment facility area. In the southwest corner of the area, there is an impoundment area measuring approximately 300 by 180 feet, with a maximum depth of 2 feet. The capacity of the impoundment area will accommodate approximately 4 inches of precipitation over the entire area. This rainfall is the anticipated maximum 24-hour precipitation, based on a 25-year storm event. Impounded water will be analyzed for contaminants prior to discharge from the facility.

The Naval Exchange (NEX) Service Station is located within the east-central portion of the Base at the southeast corner of 23rd Avenue and Dodson Street (Figure B-1). The site serves as a retail outlet for gasoline and automotive service for military personnel working at the Base. Gasoline is the only type of contamination released from this site.

Table B-1. Hazardous Compounds to be Potentially Encountered at NTL Sites

Substance	Environmental Media*	Exposure Pathways	Toxic Characteristics**
Diesel	Soil, surface water, air	Inhalation, dermal contact	Respiratory tract, headache, dizziness, nausea
Gasoline	Soil, surface water, air	Inhalation, dermal contact	Vomiting, burning of mucous membrane, throat and respiratory tract, dermatitus
Waste oil	Soil, surface water, air	Inhalation, dermal contact	Properties may vary depending on chemical
1-methylethylbenzene	Soil, surface water, air	Inhalation, dermal contact	Not available; see benzene
n-propylbenzene	Soil, surface water, air	Inhalation, dermal contact	Not available; see benzene Not available; see benzene
n-butylbenzene	Soil, surface water, air	Inhalation, dermal contact	Eye irritation, headache, confusion, excitement, nausea
Naphthalene	Soil, surface water, air	Inhalation, dermal contact	N/A
Chloromethane	Soil, surface water, air	Inhalation, dermal contact	Not available; see benzene
1,3,S-trimethylbenzene	Soil, surface water, air	Inhalation, dermal contact	Inflammation of mucous membrane
Methylene chloride	Soil, surface water, air	Inhalation, dermal contact	Inflammation of mucous membrane, weakness
Inorganic lead	Soil, surface water, air	Inhalation, dermal contact	Headaches, weakness, loss of appetite, cancer Eye irritation, liver
Benzene	Soil, surface water, air	Inhalation, dermal contact	Eye irritation, liver damage, reproduction effect

*Environmental media where hazardous materials could be encountered.
**Acute and chronic physiological symptoms of exposure to the hazardous materials that could be encountered.

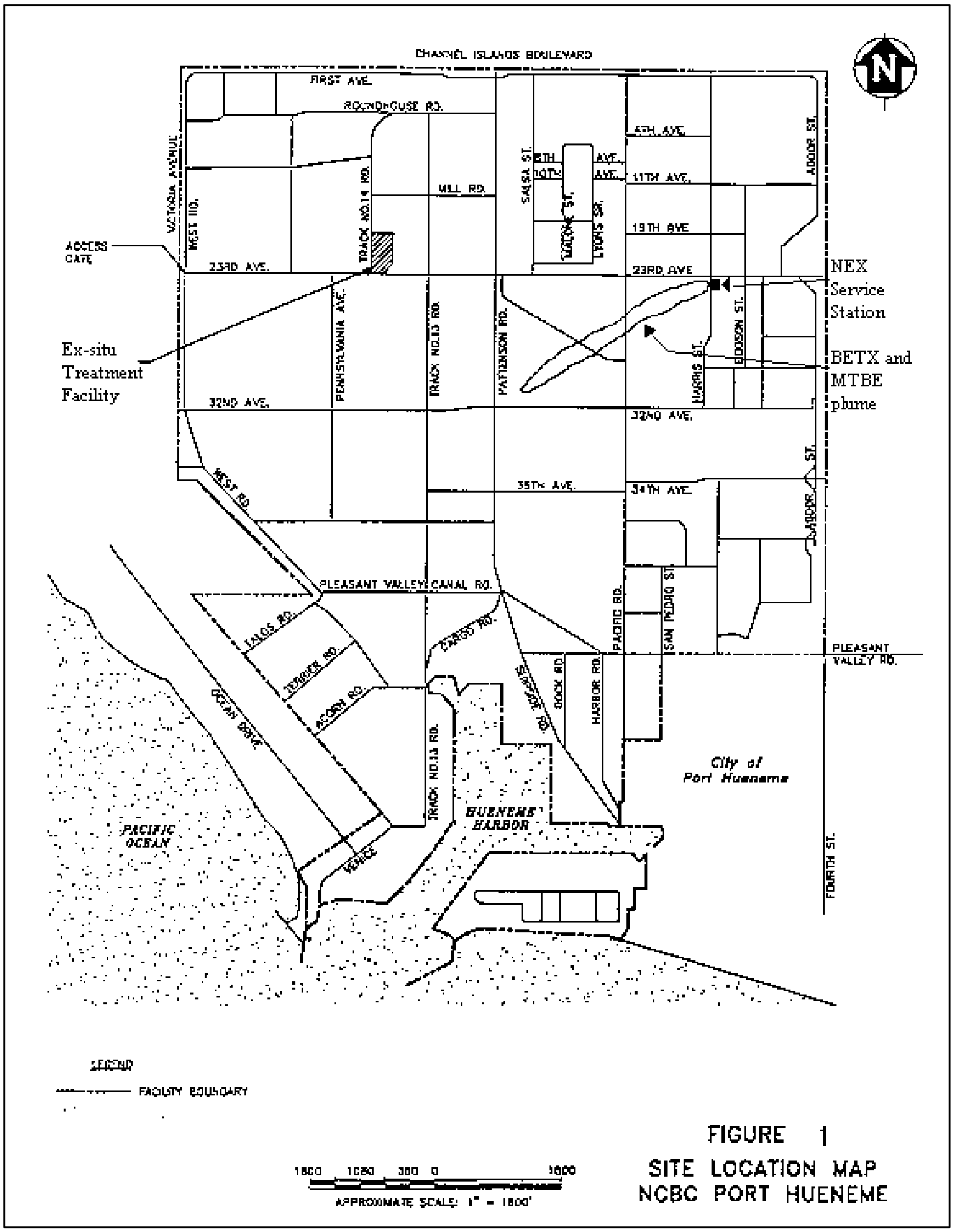

Figure B-1. National test location sites at NCBC, Port Hueneme, California, May 1997.

The predominate fuel hydrocarbon contaminated soil available for technology demonstrations at the ex-situ treatment facility is from an excavation site, Building 10, at the Naval Weapons Station (NWS) Seal Beach, California. NWS Seal Beach lies within the Los Angeles Basin. Soils underlying the site contain abundant clay and silt and are poorly drained. A semi-perched groundwater body occurs in the upper 20 to 50 feet of alluvial sand, gravel, and clay deposits and is separated from the underlying principal freshwater zone by a layer of clay and sandy clay. Water in this semi-perched aquifer is calcium bicarbonate with moderate to high total dissolved solids concentrations.

On March 12, 1991, two 10,000-gallon diesel fuel underground storage tanks were removed from the site. During a monitoring well installation, groundwater was encountered at approximately 40 feet bgs and did not contain petroleum hydrocarbons. Analysis of discolored soil samples collected during drilling indicated hydrocarbons in the soils at a depth between 16 and 21 bgs with a maximum concentration of 20,000 milligram per kilogram (mg/kg). This discolored soil was attributed to the former tanks located at those depths that contained diesel fuel and at some time in the past also contained bunker fuel or possible waste oil. The contaminated soil was excavated up to 32 feet bgs. The volume of contaminated soil was approximately 2,800 tons (1,900 cubic yards). This contaminated soil was transported to the ex-situ facility in September 1995.

In December 1984, the NCBC Public Works Department at the Base discovered free product (gasoline) during the first investigation that was conducted on the area around the NEX Station. In March 1985, it was determined that two of the fuel delivery lines that ran from USTs to the gasoline dispensers were leaking. These leaking fuel lines were thought to be the single source of contamination. Inventory records indicated that an estimated combined total of 10,800 gallons of leaded regular and premium unleaded gasoline (containing methyl tertiary butyl ether (MTBE) and 1,2-dichloroethane additives) was released to the subsurface between September 1984 and March 1985. It is not known how much was released before that time. New tanks were installed shortly after the leak was detected. In December 1992, eight additional tanks were installed and contaminated soil around both the original and the new tank pits was removed to the ex-situ treatment facility.

A semi-perched aquifer became contaminated as a result of this release. The saturated thickness of the semi-perched aquifer is about 15 feet thick from the water table to the top of the underlying clay cap. The depth to groundwater in the perched aquifer from ground surface is about 8 to 9 feet.

The land around the NEX Service Station is predominantly covered with asphalt or is occupied by buildings. There are a large number of utility lines (in service or abandoned in place) traversing the areas around the NEX Service Station, including an area containing USTs and product delivery lines. Utility lines include electrical power, natural gas, water, sanitary sewer, and storm drains. In an effort to accurately locate utility lines, site investigators reviewed the Base facility plans and performed general field surveys and a geophysical survey. Utility line depths are known or estimated to range from 1 to 9.5 feet bgs.

In 1985, 1994, 1996, and 1997, seven major studies were performed to obtain a comprehensive understanding of the nature and extent of contamination. The dissolved constituents have moved down gradient (southwestwardly) in the groundwater and formed a plume that was delineated and is currently being monitored (Figure B-1).

PERMITS

The Regional Water Quality Control Board, Los Angles Region (RWQCB), the lead regulatory agency, issued a permit to operate the ex-situ treatment facility. Soils that exceed the screening criteria for organic analysis could be treated on site and then used in the construction of landscaping berms on NCBC. The issued permit identifies residual fuel hydrocarbon and heavy metal levels that may be found in the soils used to construct landscaping berms.

For NTL contaminated aquifer sites and in-situ treatment technologies, groundwater monitoring is required by permits issued by the RWQCB. Permits identify location of wells, contaminant, and hydro-geological conditions to be measured and reporting requirements.

The Ventura County Air Pollution Control District Authority (APCD) is responsible for regulating all activities that may release air polluting compounds and particulates. All technology demonstration installed equipment, and handling and storage practices that may release fuel hydrocarbons or hazardous compound emissions will have appropriate emission controls in place. Documentation from the ACPD that authorizes Authority to Construct and Permit to Operate will identify permitted emissions and conditions for reporting monitoring of these emissions.

Contaminated Water Runoff Control

For treatment systems and stocked soil piles, high density polyethylene (>30 mil) liner and cover will be anchored to prevent rain from washing contaminated soil away from treatment system contaminant during normal or stormy conditions. The treatment units will be constructed so that rain falling directly on the treatment unit is contained. Standing water within the contained treatment zone will be removed immediately to a treatment facility or a legal disposal site, or reused within the treatment units.

Contaminant Release to Atmosphere Control

High-density polyethylene liners and covers for soil piles will be anchored sufficiently to prevent release of windblown contaminated dust and volatile contaminant fugitive emissions during normal or stormy conditions.

For technologies demonstrations, which may release volatile organic compounds (VOC), air emission treatment equipment is required to control the VOCs. Emission treatment equipment may also be needed to prevent the buildup of flammable or explosive vapors within the technology system. For most technologies, extracted VOCs are captured in activated carbon beds. These beds will be monitored for breakthrough and emission levels exceeding permit limits.

For low thermal desorption projects, the extracted vapor is constantly monitored for the lower explosive limit (LEL) of combustible gases, oxygen level, and temperature. Should the concentration of flammable vapors rise above 10 percent of the LEL, the extracted vapor is diverted through a thermal treatment unit to remove volatile hydrocarbons, reducing the

concentration of explosive vapors. Because of the concern with flammable vapors, all pipes and equipment shall be grounded, and electrical equipment shall be explosion proof.

HAZARD EVALUATION

Hazardous compounds that may be encountered during soil, sediment, and groundwater characterization and remediation demonstrations are: gasoline, diesel, waste oil, and lead. In a few treatment demonstrations, hazardous soil and water contaminated with compounds such as polychlorinated biphenyls, and chlorinated pesticides and solvents may be remediated.

Contaminated soil, sediments, and water samples and fugitive emissions will be analyzed before, during, and after treatment as part of site operations and demonstration hazard evaluation.

Field activities to be performed during technology demonstrations consist of: soil, sediments, and water handling at NTL sites; equipment installation; and soil, gas emission, and water sampling. Hazardous compounds encountered and a work task hazard analysis are provided in Tables B-1 and B-2, respectively. The NTL Management Team and Demonstration Project Team members will perform the three tasks outlined in Table B-2 and the NTL Manager will provide oversight and guidance throughout the field activities. The Material Safety Data Sheets (MSDS) included in Attachment 1 summarize the toxicological, human health, and safety information for hazardous compounds that may be encountered at the NTL sites. The following sections describe the possible exposure pathways and health effects of hazardous compounds (Table B-1).

Exposure Pathways

Exposure to hazardous compounds during field activities may occur through inhalation and dermal contact. Descriptions of these exposure pathways are provided below.

Inhalation. A principal pathway of exposure to hazardous compounds associated with site remediation is through inhalation of organic vapors and dust emanating from a potential source of contamination.

Dermal Contact. Physical contact with contaminated media during on-site work tasks is the principal pathway of exposure to nonvolatile hazardous materials. The potential for direct contact with contaminated media exists during all field work tasks. Personal protective equipment (PPE) is to be used during on-site activities and will be resistant to the substances that may be encountered.

Health Effects

The following sections describe the health effects or organic chemicals that may be encountered during site activities. Health effect information is drawn from the National Institute for Occupational Health and Safety (NIOSH). Table B-3 indicates possible chemicals and their concentrations encountered at various sites.

Table B-2. Work Task Hazard Analysis

Task	Potential Hazard	Anticipated Level of Protection*	Upgraded Level of Protection*
Task 1: Mobilize at Site	Physical**	D modified	D, C
Task 2: Remediate Soil Quarterly Sampling	Chemical, Physical**	D modified	D, C
Task 3: Transport Soil to Berm Area	Chemical, Physical**	D modified	D, C
Task 4: Technical Oversight	Chemical, Physical**	D modified	D, C

*The purpose of PPE is to shield or isolate individuals from the chemical, physical, and biological hazards that may be present in the workplace, 1910.1200(h)2(iii) - Hazard Communication Standard (additional information is found in Attachment 1).
**Includes mechanical, electrical, noise, and heat stress.

Volatile Organic Compounds. Low VOC levels may be encountered during soil remediation. Generally, VOCs are central nervous system depressants. Exposure to some VOCs may occur through skin absorption. General symptoms of VOC exposure, both acute and chronic, may include euphoria, headache, weakness, dizziness, nausea, narcosis, and possible coma. Certain VOCs are also skin and eye irritants. Workers' exposure to VOCs will be controlled by the proper use of PPE and qualitative atmospheric monitoring for organic vapors. The degree of respiratory protections used will depend on the monitoring results and the task to be performed.

Inorganic Compounds. Inorganic agents are compounds that do not contain carbon in their structure. Heavy metals such as lead are inorganic compounds. The symptoms of acute exposure to inorganic compounds consist of, but are not restricted to, abdominal pain, hypertension, anemia, insomnia, and restrictive pulmonary function. Chronic exposure to some metals may lead to the development of cancer.

Table B-3. Chemical Concentrations Projects at NTL Detected Sites

On-Site Chemical	Highest Concentration Range
Soil:	
Diesel TPH C12-C22	3,000 ppm
Gasoline TPH C4-C12	3,000 ppm
Waste Oil TPH C23-C40+	6,000 ppm
PCB Soil	31 ppm
Groundwater:	
Toluene	150 µg
Xylenes	150 µg
Ethylbenzene	250 µg
Benzene	1,300 µg
MTBE	23,000 µg
VOC (Air):	
Naphalene	120 mg/kg
Lead	8.8 mg/kg
Benzene	120 mg/kg
1-Methylethylbenzene	6.1 mg/kg
n-propylbenzene	290 mg/kg
n-butylbenzene	4.5 mg/kg
Toluene	1,700 mg/kg
Ethylbenzene	590 mg/kg
Xylenes	3,250 mg/kg
Chloromethane	6.6 mg/kg
1,3,S-trimethylbenzene	450 mg/kg
Methylene chloride	31 mg/kg

Physical Hazard

Physical hazards associated with soil remediation demonstrations present a potential threat to on-site personnel. Dangers are posed by heavy equipment, unseen obstacles, noise, and heat. Injuries may result from the following.

- Accident due to slipping, tripping, or falling
- Use of improper lifting techniques
- Moving or rotating equipment
- Equipment mobilization and operation (for example, electrocution from contact with overhead power lines)
- Equipment generating loud noises
- Heavy material falling on individuals
- Potential skin contact with contaminated soils and/or water
- Potential inhalation of dust from contaminated soil
- Any activities performed in extreme weather conditions

HEALTH AND SAFETY RESPONSIBILITIES

Site Safety Manager

The Site Safety Manager is the NTL manager who, along with the NTL Management Team, possesses a current Hazardous Waste Operations and Emergency Response (HAZWOPER) training course certificate. The NTL management team members are responsible for:

- Ensuring that planned work requirements adhere to established health and safety procedures.

- Ensuring that personnel are (1) aware of the provision of this plan, (2) instructed in the work practices necessary to ensure safety, (3) aware of planned procedures for dealing with emergencies, and (4) aware of potential hazards associated with site operations.

- Ensuring that all personnel follow health and safety procedures so that required work practices are followed.

- Correcting any work practices or conditions that may result in injury or exposure to hazardous substances.

- Preparing any accident/incident reports.

Technology Demonstration Personnel

Technology Demonstration Personnel involved in contaminated material handling, equipment installation, and project operations are responsible for:

- Preparing, reading, understanding, and complying with the requirements of the demonstration specific health and safety plan (HSP) and signing the Health and Safety Agreement Form (Attachment 2).

- Taking reasonable precautions to prevent injury to themselves and to their fellow employees.

- Implementing demonstration specific health and safety plan, and reporting any deviations from the anticipated conditions described in the plan to the NTL Manager.

- Performing only those tasks that they believe they can do safely and immediately reporting any accidents and/or unsafe conditions to the Site Safety Manager.

- Attending all required safety briefings and adhering to procedures specified therein.

TRAINING REQUIREMENTS

All personnel involved in a technology demonstration who may be exposed to on-site hazardous conditions and visitors who are participating in activities (with hands-on tasks) on NTL sites will be required to meet the training requirements outlined in 29 CFR 1910.120(e), which covers hazardous waste operations and emergency response. All personnel conducting work at the site will be required to read this health safety plan (HSP) and demonstration specific HSP. For each demonstration, the Field Project Manager will ensure that all members of the Demonstration Team have been trained to handle any unique hazardous materials.

Before beginning on-site activities, a briefing will be presented on the demonstration specific HSP for all personnel who will be participating in these activities. The following topics will be addressed during the briefing:

- Names of project leader and designated alternate.

- Hazardous compounds and project specific chemicals that may be encountered during on-site activities.

- Physical hazards that may be encountered on the site

- Levels of protection to be employed for various work tasks.

- Site control measures, including site control zones, communications, and safety work practices.

- Emergency responses and medical treatment availability and transport method to nearest emergency medical facility.

MEDICAL SURVEILLANCE

All personnel must have satisfactorily completed a comprehensive physical examination within the past 12 months. The date of physical examination of each site worker will be documented. Medical surveillance as required under 29 CFR 1910.1001 and 1926.58 is required for all personnel. This surveillance will include, but not limited to a:

- Medical and work history
- Pulmonary function testing
- Chest X-ray (at the discretion of the physician).

Nonscheduled Medical Examination

Nonscheduled medical examinations shall be conducted under the following circumstances.

- After acute exposure to any toxic or hazardous material.
- At the discretion of the NTL Manager, Field Project Manager, and/or the consulting physician when an employee has been exposed to potentially dangerous levels of toxic or hazardous materials.
- At the discretion of the NTL Manager, Field Project Manager, and/or consulting occupational physician, and at the request of an employee who has demonstrated symptoms of exposure to toxic or hazardous materials.

PERSONAL PROTECTION REQUIREMENTS

Personnel protective equipment (PPE) will be worn to protect field personnel from known or suspected physical hazards and airborne, soil borne, and waterborne contamination, in accordance with 29 CFR 1910.120. The levels of personal protection to be used for work tasks have been selected based on known or anticipated physical hazards, and concentrations of contaminants that may be encountered on site, and their chemical properties, toxicity, exposure routes, and contaminant matrices. The following sections describe levels of protection, protective equipment and clothing, limitations of protective clothing, the duration of work tasks, and respirator selection, use, and maintenance. Additional guidance is provided in Attachment 3.

Protective Equipment and Clothing

The Field Project Manager will select general levels of protection and the associated PPE ensembles for conducting various field activities (found in Table B-2). Attachment 3 provides guidance on and description of the PPE five levels of protection. In most demonstrations where the anticipated hazard level is low, field work will be performed using Level D Modified or Level D protection. If site conditions or the results of air monitoring performed during on-site activities warrant Level C protection, all field personnel will withdraw from the site, immediately notify the Field Project Manager, or an NTL Management Team member, and wait for further instructions. It is not anticipated that site activities will warrant Level A protection. However, if site activities require Level A protection, the Field Project Manager will determine the appropriate level on a task-specific basis.

Duration of Work Tasks

The duration of site activities involving use of PPE will be established by the Field Project Manager, or a designee, and will be based on ambient temperature and weather conditions, the capacity of personnel to work in the designated level of PPE (taking into account such conditions as heat stress), and the limitations of the PPE. All rest breaks will be taken in the support zone after decontamination and removal of PPE.

ENVIRONMENTAL SURVEILLANCE

Air monitoring will be performed during designated on-site work tasks to protect field personnel against exposure to airborne hazardous substances and to determine appropriate levels of PPE for work tasks. The following sections discuss initial air monitoring, periodic air monitoring, monitoring parameters, use and maintenance of survey equipment, heat stress monitoring, and cold stress monitoring.

Initial Air Monitoring

Initial air monitoring of the work area will be performed before beginning any work task. This monitoring will be performed using real-time field survey instrumentation, such as a photoionization detector (PID) and/or an organic vapor analyzer (OVA), to determine the levels of airborne organic contaminants. These levels will also be monitored to identify background contaminant concentrations and to detect any potentially hazardous situation that might have developed during off-shift periods. All monitoring readings shall be recorded in a field logbook and maintained by the Field Project Manager and a copy forwarded to the NTL management team.

Periodic Air Monitoring

Periodic air monitoring will be performed during all site activities. This type of monitoring will be performed as a minimum requirement when the following situations arise:

- Work begins on a different portion of the site.
- Contaminants other than those previously identified are encountered.
- A different type of operation is initiated.
- Work in areas with obvious liquid contamination.
- Workers experience physical difficulties.

Monitoring Parameters

Air monitoring for VOCs will be performed at shoulder height (in the breathing zone) on workers most likely to be exposed to potentially hazardous concentrations of contaminants. During fuel hydrocarbon contaminated soil handling, a sustained reading of 20 units on the OVA and/or PID, measured within the breathing zone, will be the action level used by the Field Project Manager to specify when respiratory protection measures for organic vapors shall be implemented. In addition, respiratory protection should be donned if odors or dust levels become objectionable at any time during technology demonstration activities.

Monitoring Equipment

All personnel using field monitoring equipment will be briefed on its operation, limitations, and maintenance. Maintenance and calibration will be performed in accordance with manufacturer guidelines by a designated individual familiar with the devices and maintenance procedures. Repairs, maintenance, and routine calibration of these devices will be recorded in an equipment

maintenance logbook that will be signed. The equipment maintenance logbook for each instrument will be kept in that instrument's case.

Air monitoring equipment (such as PIDs or OVA) will be calibrated before work begins. On-site personnel will perform routine maintenance (changing batteries or lamps and cleaning lamps and fans). A trained service technician will perform any additional maintenance.

Heat Stress Monitoring

Heat stress is a common and serious illness at hazardous waste sites. Heat stress depends on such factors as environmental conditions, clothing and the type of PPE required for the work task, workload, and the worker's physical condition. Some types of PPE are heavy and they increase the body's normal heat exchange mechanisms.

- Heat stress may be of particular concern when the dry-bulb air temperature exceeds 70°F. Depending on the degree and nature of possible heat stress to be encountered on site, the following heat stress control actions may be necessary:

- Provide adequate liquids to replace lost body fluids. These liquids can be water, commercial mixes combined with potable water, or commercial liquids (such as Gatorade).

- Establish a work regimen that will provide adequate rest periods for cooling down. This action may require additional shifts for workers for earlier or later work schedules.

- Require removal of impermeable protective garments during rest periods.

- Ensure that all rest periods are taken in a shaded rest area, if possible.

- Regulate rest periods, and ensure that workers will not be assigned other tasks during rest periods.

- Notify all workers of health hazards and the importance of adequate rest, acclimatization, and proper diet; teach workers to recognize heat stress and to conduct first aid to prevent heat stress.

Cold Stress Monitoring

Cold stress may be of particular concern when a wind chill-adjusted temperature of 10°F or less is expected. This condition is not anticipated at any NCBC site.

SITE CONTROL AND SAFE WORK PRACTICES

The following sections describe the NTL hazardous waste sites control and visitor access, and safe work practices.

Exclusion Zone

A defined exclusion zone will be established at the site during certain field operations, depending on type and contamination levels. Visitors will not be permitted to enter the exclusion zone without the authorization of the field project manager.

Emergency Communication Signals. The following hand signals will be used by site personnel in emergency situations or when verbal communication is difficult:

Signal	Definition
Hands clutching throat	Out of air cannot breathe
Hands on top of head	Need assistance
Thumbs up	Okay, I am all right, I understand
Thumbs down	No, or negative
Arms waving upright	Send backup support
Gripping partner’s wrist	Exit area immediately

Emergency Air Horn Signal

HELP	Three short blasts
EVACUATION	Three song blasts
ALL CLEAR	Alternating long and short blasts

Contamination Reduction (Decontamination) Zone

The contamination reduction zone is a transition zone between the exclusion zone and the support zone. A decontamination line will be established within the contamination reduction zone. The decontamination station will contain facilities to decontaminate personnel and portable equipment. Visitors will not be permitted to enter the contamination reduction zone unless authorized by the Field Project Manager.

Support Zone

The support zone will be situated in a clean area outside the contamination reduction zone, where the chance of encountering hazardous materials or conditions is minimal. Visitors will be permitted to enter this zone.

Visitor Access

All visitors must receive prior approval from the NTL Management Team or Field Project Manager, and may do so only for the purposes of observing site conditions or operations. Visitors will be required to contact an NTL Management Team member or Field Project Manager on arrival at the site. Each visitor will be given a safety orientation. Visitors shall be escorted when near the operations area and will not be allowed into areas while contaminated

soil, sediments, or water is being handled or equipment is being installed unless training and medical requirements have been met and documentation provided.

Safe Work Practices

Safe work practices for site activities include the following.

- All site personnel will enter a designated exclusion zone through the contamination reduction corridor. All personnel leaving the exclusion zone must exit through the contamination reduction corridor and undergo the contamination reduction zone, decontamination procedure.

- Only vehicles and equipment necessary to complete work tasks (such as support trucks) will be permitted within an exclusion zone. All nonessential vehicles and equipment will remain within the support zone.

- Containers (such as drums) will be moved only with proper equipment and will be secured to prevent dropping or loss of control during transport.

- All personnel will avoid contact with potentially contaminated substances. Walking through puddles or mud and kneeling on the ground will be avoided whenever possible.

- Equipment will not be placed on potentially contaminated surfaces.

- Portable eyewash stations will be located near the site.

- Food and beverages will not be permitted in the exclusion zone or the contamination reduction zone. Possession or use of tobacco products and application of cosmetics are also prohibited in these areas.

- Matches and lighters will not be permitted in the exclusion zone or contamination reduction zone.

- During rest periods, all personnel will be required to wash their hands and faces before eating, drinking, smoking, or applying cosmetics.

- Site personnel will observe each other for signs of toxic exposure and heat or cold stress. Indications of adverse effects include but are not limited to the following:

  Changes in complexion and skin discoloration
  Changes in coordination
  Changes in demeanor
  Excessive salivation and pulmonary response
  Changes in speech patterns

- Site personnel will inform each other of non-visual effects of illness, such as the following: Headache, dizziness, nausea, blurred vision, cramps, irritation of eyes; skin; or the respiratory tract

Use of Heavy Equipment. Truck-mounted heavy equipment, drilling rigs, and field trucks, as well as movable soil conveyed systems, are among the types of equipment that may be used. Heavy equipment can present a substantial hazard to workers. General requirements for motor vehicles and material handling equipment are provided in the OSHA Construction Industry Standards, 29 CFR 1926, Subpart O. All heavy equipment operators shall be trained on and licensed for use of the type of equipment being operated. Attachment 4 contains heavy equipment site safety.

Avoiding Electrical Hazards. Electrical wiring, if used during site activity, will satisfy the requirements of 29 CFR 1926, Subpart K, and any applicable local electrical codes. Some specific electrical safety requirements are listed below:

- All extension cords must have functional grounding conductors and be in good condition.

- All equipment that is not double insulated must have a functional grounding conductor.

- Instead of a documented "assured equipment grounding conductor program," ground fault protected circuits may be used.

- Maintenance on electrical equipment will be performed only after proper lockout procedures have been followed.

Avoiding Trip and Fall Hazards. Workers will be informed of any potential trip and fall hazards during regular health and safety meetings. Whenever possible, trip and fall hazards will be eliminated or clearly identified with yellow caution tape.

Avoiding Excessive Noise Exposure. Workers and site visitors will be protected from excessive noise exposure by means of equipment maintenance, noise monitoring, and hearing conservation programs that comply with 29 CFR 1926.52. Hearing protection will be required if the sound level continuously equals or exceeds 85 decibels on the A-weighted scale or if the sound level exceeds 140 decibels regardless of the duration of exposure.

Ear inserts with a noise reduction rating of at least 26 decibels on the A-weighted scale or similar equipment will be provided. Such equipment will be worn during work tasks involving heavy equipment, internal combustion engines, drilling rigs, or other sources of elevated noise levels.

SANITATION

Potable water, drinking cups, toilet facilities, washing facilities, and other sanitation requirements will be provided in compliance with specifications of 29 CFR 1926.51.

Site Housekeeping

Potentially hazardous wastes generated during site activities will be drummed, if necessary, and handled in accordance with Resource Conservation and Recovery ACT (RCRA) requirements. Non-hazardous waste and debris will be disposed of as standard municipal waste.

Decontamination

Decontamination is the process of removing from or neutralizing contaminants on personnel or equipment. When properly conducted, decontamination procedures protect the worker from contaminants that may have accumulated on PPE, tools, and other equipment. Proper decontamination also prevents transport of potentially harmful materials to unaffected areas. Personnel and equipment decontamination procedures are described in the following sections.

Personnel Decontamination. Minimal personnel decontamination is anticipated for NTL sites because disposable PPE will be used. Personnel and reusable PPE will be decontaminated with potable water or a mixture of detergent and water. Attachment 2 contains guidance on decontamination procedures. Liquid and solid wastes produced during decontamination will be collected and drummed.

Equipment Decontamination. Decontamination of all sampling and field monitoring equipment used during site activities will be required. The equipment decontamination procedures described in the following sections are based on guidelines appropriate for low-level contamination. When appropriate, Liquinox or Alconox cleaning solution and deionized water rinses will be used to decontaminate equipment. Wastewater from equipment decontamination activities will be stored in 55-gallon drums until proper disposal is possible.

Sampling equipment, such as split-spoons, will be decontaminated before and after each use. Distilled water will be used for the following sampling equipment decontamination procedures.

- Scrub the equipment with a brush in a bucket containing Liquinox or Alconox solution and potable, distilled water.

- Triple-rinse the equipment with distilled water and allow it to air dry.

- Reassemble the equipment and place it in a clean area on plastic or aluminum foil. If aluminum foil is used, wrap the equipment with the dull side of the aluminum foil toward the equipment.

EMERGENCY CONTINGENCY PLANNING

The NTL Management Team will be notified of any on-site emergencies and will be responsible for ensuring that the Field Project Manager follows appropriate emergency procedures. Standard emergency procedures to be used by site personnel are described in the following sections. Figure B-2 indicates location of nearest hospital and urgent care clinic.

Injury in the Exclusion or Contamination Reduction Zone

In the event of an injury in the exclusion zone or CRZ, all personnel will exit the exclusion zone and assemble at the decontamination line. The Field Project Manager will be immediately notified of the event if necessary. The Field Project Manager will contact an NTL Manager Team member, and together they will evaluate the nature and extent of the injury. The affected person will be decontaminated to the extent practical before moved to the support zone. Appropriate first aid procedures will be performed, an immediate request for an ambulance will be made (if necessary), and the designated medical facility will be notified (if necessary). No personnel will re-enter the exclusion zone until the cause of injury or illness is determined and re-entry is considered safe. In case of severe injury, the Field Project Manager will implement procedures to minimize the possibility of further injury. If the need to transport the patient to the medical facility supersedes the need to decontaminate the patient, the medical facility will be notified that the patient has not been decontaminated before the patient arrives.

Injury in the Support Zone

If an injury occurs in the support zone, the Field Project Manager will be notified immediately. Appropriate first aid will be administered and, if necessary, the injured individual will be transported to the designated medical facility. If the injury does not affect the safety or performance of site personnel, operations will continue.

Fire or Explosion

In the event of a fire or explosion at the site, the Port Hueneme Fire Department will be contacted as soon as possible at 911 and evacuation of the site will begin immediately.

Protective Equipment Failure

If any worker in the exclusion zone experiences a failure of protective equipment that affects his or her personal protection, the worker and all coworkers will immediately leave the exclusion zone. Re-entry to the exclusion zone will not be permitted until the protective equipment has been repaired or replaced and the cause of the equipment failure has been determined and is no longer considered a threat.

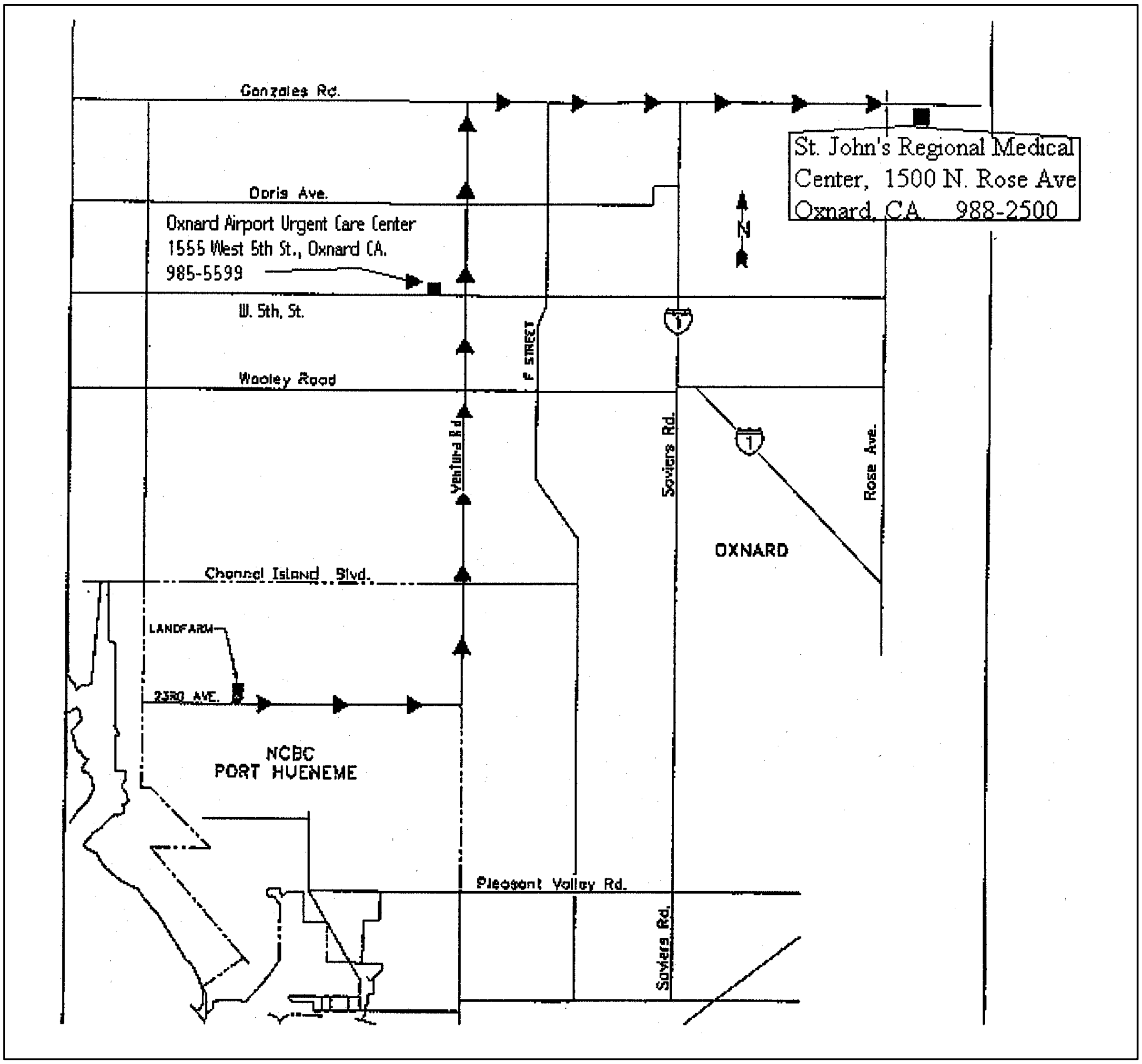

Figure B-2. Emergency clinic and hospital routes.

Personnel Exposures

Eye Exposure. Immediately flush the eyes with distilled water (portable eyewash). Transport for examination and treatment.

Skin Exposure. Remove contaminated clothing and treat by washing with waterless hand cleaner and paper towels followed by soap and water.

Inhalation. If a person inhales a large amount of organic vapor, remove the person from the work area to fresh air and administer artificial respiration if breathing has ceased. Transport the affected person to the nearest hospital or urgent care clinic if overexposure to lungs has occurred.

Physical Injuries. In case of physical injury, the victim may receive emergency first aid at the site, as appropriate, and if necessary, will be transported by ambulance to nearest hospital or urgent care clinic. An accident form must be completed for any accident or occupational exposure.

Emergency Information Telephone Numbers

Emergency Service	Telephone Number
Local Police Department	911
Local Fire Department	911
Local Hospital	St. John's Regional Medical Center (805) 988-2500
Urgent Care Clinic	(805) 985-5599
Local Ambulance Service	911
Poison Control Center	(800) 822-3232
National Response Center	(800) 424-8802
CHEMTREC Chemical Transportation Emergency Center	(800) 424-9300

Hospital and Urgent Care Clinic Route Directions

Before performing any site activities, personnel will become familiar with routes to the hospital and nearest urgent care clinic. A map indicating routes is provided in Figure B-2.

SPILL CONTAINMENT PROGRAM

The procedures defined in this section comprise the spill containment program in place for activities at the site:

- All drums and containers used for containing waste materials shall meet the appropriate Department of Transportation (DOT), Occupational Safety and Health Administration (OSHA), and Environmental Protection Agency (EPA) regulations for the waste that they will contain.

- Drums and containers shall be inspected and their integrity assured prior to being moved.

- Drums or containers that cannot be inspected before being moved because of storage condition shall be positioned in an accessible location and inspected prior to further handling.

- Operations on-site will be organized so as to minimize the amount of drum or container movement.

- Employees involved in drum or container operations shall be warned of the hazards associated with the containers.

- Drums or containers that cannot be moved without failure or potential failure shall be emptied into a second drum or placed in an oversized container.

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ATTACHMENT 1

SITE SPECIFIC MSDS (MATERIAL SAFETY DATA SHEETS)

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Need to “place” site specific MSDS

ATTACHMENT 2

PROTECTIVE EQUIPMENT AND CLOTHING

The following general levels of protection and the associated PPE ensembles have been selected for use by field personnel during field activities (Table B-2). Because the anticipated hazard level is low, field work will be performed using Level D Modified or Level D protection. If site conditions or the results of air monitoring performed during on-site activities warrant Level C protection, all field personnel will withdraw from the site, immediately notify the Field Project Manager, or NTL Manager Team member, and wait for further instructions.

Level D

- Coveralls or work clothes, if applicable
- Steel-toed boots with shanks
- Hard hat
- Disposable boot covers (when entering wet or muddy areas with known elevated contamination levels, such as previously excavated waste areas)
- Hearing protection (for areas with a noise level exceeding 85 decibels on the A-weighted scale)

Level D Modified

- Coveralls or work clothes
- Steel-toed boots with shank
- Hard hat (face shield)
- Disposable gloves (latex or nitride)
- Hearing protection (for areas with a noise level exceeding 85 decibels on the A-weighted scale)

Level C

- Coveralls or work clothes, if applicable
- Chemical-resistant clothing (Tyvek™ or Saranex™), if applicable
- Outer gloves (neoprene or nitrile), if applicable
- Outer gloves (latex or polyvinyl chloride), if applicable
- Inner gloves (cotton liners)
- Steel-toed boots with shanks
- Disposable boot covers or chemical-resistant outer boots

- Full- or half-face air-purifying respirator with National Institute for Occupational Safety and Health (NIOSH) approved cartridges to protect against organic vapors, dust, fumes, and mists
- Safety glasses or goggles (with half face respiratory only)
- Hard hat (face shield optional)
- Hearing protection (for areas with a noise level exceeding 85 decibels on the A-weighted scale)

Level B

- Chemical-resistant clothing (Tyvek™ or Saranex™)
- Outer gloves (neoprene or nitrile)
- Outer gloves (latex or polyvinyl chloride) if applicable
- Inner gloves cotton liners
- Steel-toed boots with shanks
- Disposable boot covers or chemical-resistant outer boots
- Positive-pressure, demand type air respirator with airline respirator and air cylinder, or self-contained breathing apparatus (SCBA) approved by NIOSH
- Hard hat (face shield optional)
- Hearing protection (for areas with a noise level exceeding 85 decibels on the A-weighted scale)
- Tape connecting gloves to sleeves and cuffs, also to boots if necessary

RESPIRATOR SELECTION

Respirator use is not anticipated for the site. If necessary, a full- or half-face, air-purifying respirator equipped with NIOSH approved cartridges will be selected for use to protect against organic vapors, dust, fumes, and mists. Respirators will be selected by the Field Project Manager, based on knowledge of the substances that may be present and the concentrations of compounds previously encountered at the site. Air-purifying respirators will be used only in conjunction with breathing zone air monitoring, which must be conducted with adherence to the action limits. Air-purifying respirators will be used only when the devices can provide protection against the substances encountered on site. Factors precluding the use of air-purifying respirators are as follows:

- Oxygen deficient atmosphere (less than 19.5)

- Concentrations of substances that may be immediately dangerous to life and health, as defined in the Material Safety Data Sheets found in Attachment 1.

- Unknown contaminant concentrations, or concentrations that may exceed the maximum use levels of 1,000 parts per million (ppm) for the designated cartridges, in accordance with the selected cartridge manufacturer's instructions.

- Unidentified contaminants.

- High relative humidity (which reduces the absorbent life of the cartridges).

- Identified substances with inadequate warning properties (for example, they are tasteless, odorless, and invisible), and respirator cartridges with an unknown absorbent service life, and respirator units with no end of service life indicator.

- Respirators will be inspected daily, and any necessary repairs will be made during the time of inspection. Damaged respirators will be properly disposed of.

LIMITATIONS OF PROTECTIVE CLOTHING

PPE clothing ensembles designated for use during site activities have been selected to provide protection against contaminants at known or anticipated concentrations in soil and water matrices. However, no protective garment, glove, or boot is entirely chemical-resistant, nor does any protective clothing provide protection against all types of chemicals. Permeation of a given chemical through PPE depends on contaminant concentrations, environmental conditions, the physical condition of the protective garment, and the resistance of the garment to the specific contaminant. Chemical permeation may continue even after the source of the contamination has been removed from the garment.

To obtain optimum use from PPE, site personnel must:

- When using Tyvek™ or Saranex™ coveralls, don a new, clean garment after each rest break or at the beginning of each shift.

- Inspect all clothing for non-uniform coatings, tears, and poorly functioning closures.

- Inspect reusable garments, boots, and gloves both before and during use for visible signs of chemical permeation such as swelling, discoloration, stiffness, brittleness, cracks, any sign of puncture, and any sign of abrasion.

- Discard any reusable gloves, boots, or coveralls exhibiting any of the characteristics listed above. PPE clothing used in areas with known or suspected elevated concentrations of contaminants should not be reused. Reusable PPE will be decontaminated in accordance with the following and will be neatly stored in the support zone, away from contaminants.

DECONTAMINATION PROCEDURES

The following decontamination procedures will be conducted if personnel decontamination is required:

- Wash neoprene boots with a Liquinox or Alconox solution, and rinse them with water. Remove and retain neoprene boots for reuse, if possible.

- Place disposable booties in plastic bags for disposal.

- Remove Tyvek™ or Saranex™ body suit and place it in a plastic bag for disposal.

- Remove the air-purifying respirator, if used, and place the spent filter in a plastic bag for disposal. The filter may be changed daily or at longer intervals, depending on the use and application. Clean and disinfect the respirator with towelettes or a nonphosphate cleaning solution. Place it in a plastic bag for storage.

- Remove inner gloves and place them in a plastic bag for disposal

- Thoroughly wash hands and face with water and soap.

- Collect used disposable PPE in 55-gallon drums and disposed of as municipal waste, unless otherwise specified.

Further personnel decontamination procedures may be established as needed.

The Field Project Manager will continuously monitor the effectiveness of the respiratory protection program.

If a respirator is used by more than one person, clean and disinfect the respirator with benzoalkaloid or isopropyl alcohol after each use. Cartridges will be changed at the end of each shift or at breakthrough, whichever occurs first. After being cleaned, respirators will be placed in clean, plastic bags and stored in the support zone. The following respirator inspection and cleaning procedures will be followed whenever respirator protection is used.

Daily inspection, checkout, and cleaning procedures are:

- Visually inspect the entire unit for obvious damage and deteriorated rubber.

- Inspect the face piece harness for damage.

- Inspect the lens for damage, and make sure the face piece has the proper seal.

- Pull off the plastic cover of the exhalation valve; check the valve for debris and tears in the neoprene that could cause leakage.

- Unscrew the cartridges of both inhalation valves, and visually inspect the neoprene valves for tears. Make sure the inhalation valves and cartridge receptacle gaskets are in place.

- Make sure a protective cover is attached to the lens.

- Make sure the speaking diaphragm retainer ring is hand-tight.

Don the respirator, and perform the negative pressure test.

Weekly cleaning procedures are:

- Disassemble the respirator in the support zone by removing the cartridges, damaging them to prevent accidental reuse, and discarding them. To clean the respirator thoroughly, remove the inhalation and exhalation valves, speaking diaphragm, and any hoses.

- To clean the respirator, dissolve cleaning and disinfecting solution (usually provided by the manufacturer) in a tub with warm water. With gloved hands, swirl the respirator in the tub for at least 1 minute. A soft brush may be used to help clean the respirator.

- Rinse the cleaned and disinfected respirator thoroughly with potable water to remove all traces of detergent and disinfectant. This step is very important in preventing dermatitis.

- Air dry the respirator on a clean surface. The respirator may also be turned upside-down, but care must be taken not to damage or distort the face piece.

- Reassemble the clean, dry respirator and inspect it in an area separate from the disassembly area to avoid contamination. Inspect the respirator carefully for detergent or soap residue left by inadequate rinsing. Residue appears most often under the seat of the exhalation valve and can cause valve leakage or sticking.

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ATTACHMENT 3

HEALTH AND SAFETY COMPLIANCE AGREEMENT FORM

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HEALTH AND SAFETY COMPLIANCE AGREEMENT FORM

We, the undersigned, have individually read and will follow the health and safety guidelines presented in this Health and Safety Plan and will follow them while performing on-site work.

NAME/TITLE/ORGANIZATION **DATE**

ATTACHMENT 4

HEAVY EQUIPMENT SAFETY

The following precautions will be followed when heavy equipment (such as front-end loaders, drilling rig) are in use:

- The operator will inspect the heavy equipment before each work shift. The responsible manager (NTL Management Team Member or Field Project Manager) will ensure compliance this precaution.

- Equipment operators will be instructed to report any abnormalities, such as equipment failure, oozing liquids, and unusual odors, to their supervisors or the Field Project Manager. Improperly maintained equipment will not be used.

- Only qualified and licensed personnel will operate heavy equipment.

- Hard hats, steel-toed boots, and safety glasses or goggles will be worn at all times around heavy equipment. Loose-fitting clothing and loose, long hair will be prohibited around moving machinery.

- Workers will not assume that the equipment operator is keeping track of their exact location.

- Workers will never walk directly behind or to the side of heavy equipment without the operator's knowledge.

- Workers will maintain visual contact with equipment operators at all times.

- When an operator must maneuver equipment in tight quarters, a second person will be required to ensure that there is adequate clearance. If much backing is required, two ground guides will be used: one in the direction of the equipment that is moving, and the other in the operator's normal field of vision to relay signals.

- All heavy equipment will be kept in the exclusion zone until the work has been complete. Such equipment will then be decontaminated within the designated decontamination area.

- Hand signal communications will be established when verbal communication is difficult. One person per work team will be designated to give hand signals to equipment operators.

- Equipment with an obstructed rear view must have an audible alarm that sounds when the equipment is moving in reverse (unless a spotter guides the operator).

- Parking brakes will be kept engaged when equipment is not in use.

- Blades, buckets, dump bodies, and other hydraulic systems will be kept fully lowered when equipment is not in use.

- Equipment cabs will be kept free of all nonessential and loose items.

- Seat belts must be present in all vehicles having rollover protective structures (ROPS).

- With certain exceptions, all material handling equipment will be provided with ROPS.

- Material handling equipment that lacks ROPS will not be operated on a grade unless the grade can safely accommodate the equipment involved.

- Use only chains, hoists, straps, and other equipment that will safely aid transport of heavy materials.

- Use proper personal lifting techniques.. Workers will lift using their legs, not their backs.

- Make sure that no underground or overhead power lines, sewer lines, gas lines, or telephone lines present a hazard in the work area.

- Keep all personnel who are not essential to work activities out of the work area.

- Workers will be aware of their footing at all times.